Los Angeles County Department of Public Works

SEDIMENTATION MANUAL

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SEDIMENTATION MANUAL

Hydraulic/Water Conservation Division
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1. INTRODUCTION

A. ACKNOWLEDGEMENT

A group consisting of Isaac Gindi, Mariette Schleikorn, William Ward, Belinda Kwan, Loreto Soriano, Glenn Howe, Mahdad Derakhshani, Hartun Khachikian, Martin Moreno, and Allen Ma prepared this manual under the principal direction of Sree Kumar and David Potter. An overview committee comprised of Eric Bredehorst, Alan Bentley, Chander Garg, Sree Kumar, Iraj Nasseri, and David Potter reviewed the contents of the Manual. Mr. Garvin Pederson, Mr. Reza Izadi, and Mr. Michael Anderson supervised the entire project. Also providing assistance were Laurel Putnam, Mooler Ang, Michael Miranda, Sanjay Thakkar, Phat Ho, and Darrell Yip.

B. PURPOSE AND SCOPE OF MANUAL

This manual establishes the Los Angeles County Department of Public Works' sedimentation design criteria. The procedures and standards contained in this manual were developed mostly by the Hydraulic/Water Conservation Division of Los Angeles County Department of Public Works as the need arose to design erosion control structures, sediment retention structures, and channels carrying sediment laden flows. These sedimentation techniques are applicable in the design of local debris basins, storm drains, retention and detention basins, and channel projects.

Some sections of this Manual were previously part of the Department's Hydrology Manual. When the Sedimentation Manual was developed, all information in the Hydrology Manual (March 1989 Edition) related to sedimentation was transferred into this manual. The hydraulic and structural design considerations are covered in the Department's Hydraulic Design Manual (March 1982 Edition) and the Department's Structural Design Manual (April 1982 Edition). For detailed debris basin design, refer to the Department's Debris Dams and Basins Design Manual.

Reference material and design examples are located in the Hydrology/Sedimentation Manual Appendix.

The Department distributed copies of the Hydrology/Sedimentation Manual and Appendix to members of the Land Development Advisory Committee (LDAC) for their review. The members who responded indicated that they had no comments on the Sedimentation Manual.

C. FACTORS AFFECTING SEDIMENT PRODUCTION

Sediment production from a watershed is a function of several variables, the most evident of which in Los Angeles County are: vegetative cover, rainfall intensity, slope of the watershed, geology, soil type, and size of drainage area.

Fire greatly increases the amount of runoff and erosion from a mountain watershed. A recently denuded watershed will produce greater than normal sediment volumes due to higher runoff caused by a lack of vegetation and lowered infiltration rates. The inclusion of sediment in runoff results in a greater total discharge. This is referred to as bulking.

Flood flows from a denuded watershed can transport large quantities and sizes of sediment. Sediment production from a major storm has amounted to as much as 120,000 cubic yards per square mile of watershed. Boulders up to eight feet across have been deposited in valley areas a considerable distance from their source. Sediment discharge from a major storm can be equal to the actual storm runoff, that is, runoff bulked 100 percent.

D. FACTORS AFFECTING SEDIMENT TRANSPORT

Sediment transport depends on several factors such as particle size, shape, specific gravity, flow velocity, and depth. The ability of a stream to transport sediment increases as discharge increases and as stream-bed gradient increases.

There are three forms of sediment movement evident in Los Angeles County:

D-1. General Sediment Transport

Sediment is transported as bed load or suspended load. Bed load is mostly transported by sliding, rolling, and bouncing over the bed. Suspended load is the portion of the load which is supported by turbulent eddies. Suspended load includes the finer portion of the bed material which is only intermittently suspended within the flow, as well as wash load, which consists of particles too fine to settle to the channel bed.

D-2. Mud Floods

A flood in which the water carries heavy loads of sediment, generally between 20 to 45 percent by volume, is referred to as a mud flood. Mud floods typically occur in watercourses or on alluvial fans discharging from mountainous regions, although they may occur on less mountainous flood plains as well. Conventional hydraulic analysis using momentum, energy, and continuity theories are applicable, provided appropriate parameters are used.

D-3. Mudflows

A mudflow is a specific subset of landslides where the flow has sufficient viscosity to support large boulders within a matrix of smaller-sized particles. Mudflows may be confined to drainage channels or may occur unconfined on hill-slopes and alluvial fans. The concentration of sediment is generally higher than mud floods (typically 45 to 60 percent by volume). Mudflows are generally treated as viscoplastic fluids and are analyzed using non-Newtonian theory.

The hydromechanics of mud floods and mudflows are not covered in this manual.

2. DEPARTMENT POLICY ON LEVELS OF FLOOD PROTECTION

A. POLICY FOR SEDIMENT IN THE FLOW

A Department of Public Works memorandum that established the policy on levels of flood protection for hydrologic design is included in the Hydrology Manual (see Section 2 of the Hydrology Manual titled Department Policy on Levels of Flood Protection). That policy provides instructions on which design storm or rainfall frequency to use in developing runoff rates. This section discusses the additional requirements if the flow includes sediment.

A-1. Capital Flood Protection

The following facilities and structures must be designed for the Capital Flood. The Capital Flood is the burned and bulked (where applicable) runoff from a 50-year frequency design storm falling on a saturated watershed. For burn factors see the Hydrology Manual, and for bulking see Section 3.C of this Manual.

A-1.1. Natural Watercourses

The Capital Flood level of protection applies to all facilities, including open channels, closed conduits, bridges, and dams and debris basins, that are constructed to transport or intercept sediment laden flood waters from natural watercourses. Dams that are under the State of California (D.S.O.D.) jurisdiction must also meet the Probable Maximum Flood criteria (see Hydrology Manual Sections 2.A-3 and 3.E).

A natural watercourse is typically a path along which water flows due to natural topographic features. Refer to the Hydrology Manual Section 2.A for more detail.

A-1.2. Sediment Retention Facilities

The Capital Flood level of protection applies to all retention basins and detention basins designed to intercept sediment-laden flood waters.

Sediment retention basins must be designed to handle the design sediment volume. Refer to Section 3 for Sediment Production and Delivery and to Section 4 for details on sediment control facilities.

A-1.3. Culverts

The Capital Flood level of protection applies to all culverts that pass sediment-laden flood waters under public roads.

A-1.4. Facilities with Tributary Areas Subject to Sediment Production

For any facility, apply the Capital Flood to all undeveloped tributary areas that are likely to produce sediment, whether or not the areas are likely to burn.

B. SANTA CLARA RIVER & MAJOR TRIBUTARIES-DRAINAGE POLICY

The Santa Clara River Basin is the second largest of the eight moderately developed drainage basins in Southern California and a major source of sediment for the beaches along the coast. In addition, the groundwater basins that underlie the Santa Clara River are an important source of water for the valley. It is important that the groundwater basins continue to be recharged by streambed percolation.

The following standards have, therefore, been adopted by the Department of Public Works to maintain, as closely as possible, the environmental balance that exists in the Santa Clara River Basin. Note these standards supersede all previous standards and reports written for the Santa Clara River Basin.

I. The design of flood protection facilities for the Santa Clara River shall be based on the following:

   a. The Department Capital Flood flow rates (50-year rainfall Q, bulked only).
   b. Soft bottom waterways with levees.
   c. Protective levees and additional facilities such as drop structures or stabilizers as required, shall be designed using Department criteria.

II. The design of flood protection facilities for major tributaries of the Santa Clara River that have been mapped by the Department as a floodways (see Figures 2.1 and 2.2) or have a flow rate of 2,000 cubic feet per second (burned and bulked Q[1]) or greater as determined by the Department's Capital Flood hydrology shall be based on items b and c above.

III. The design of flood protection facilities for tributary streams to the Santa Clara River that have existing flood control improvements shall be compatible with these existing facilities. See Attachment A.

IV. The soft bottom waterways shall be designed to maintain an equilibrium between sediment supply to the waterway and sediment transport through the waterway. In cases where a soft bottom waterway is subject to significant deposition due to high sediment supply or significant erosion due to lack of sediment supply, then the drainage concept shall be discussed with the Department prior to submitting plans.

The following criteria was added in response to comments made by the public on the previous policy:

1. Covered sections of natural bottom channels shall primarily be limited to street crossings.

2. Whether a bridge or a culvert is required for a road crossing over a soft-bottom channel depends on the flow rates and the magnitude of debris. Short culverts may be acceptable under certain cases, but in general bridges shall be anticipated.

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[1] The Department's Capital Flood flow rates (50 year rainfall Q, burned and bulked).

TABLE 2.1 - ATTACHMENT A
DRAINAGE FACILITIES FOR
THE SANTA CLARA RIVER AND MAJOR TRIBUTARIES

Main River / Tributary	Current Improvement	Compatible Future Channel Improvement
Santa Clara River	Soft bottom with protective levee	Soft bottom with stabilizers where necessary
Tick Canyon	Lower reach-concrete channel	Upper reach-concrete channel with debris control
Mint Canyon	Lower reach-concrete channel	Middle reach-concrete channel Upper reach-soft bottom with stabilizers
Bouquet Canyon	Middle reach-soft bottom with stabilizers	Lower and Upper reaches-soft bottom with stabilizers
Dry Canyon	Lower reach-concrete channel	Upper reach-concrete channel
Haskell Canyon	Lower reach-concrete channel	Upper reach-soft bottom with stabilizers
Plum Canyon	Lower reach-concrete channel	Upper reach-concrete channel with debris control or soft bottom with stabilizers
South Fork - Santa Clara	Lower reach-soft bottom with stabilizers Middle reach-concrete channel	Lower reach-soft bottom with stabilizers Upper reach-concrete channel with debris control.
Pico Canyon	Lower reach partly soft bottom with stabilizers partly concrete channel	Upper reach-soft bottom with stabilizers
San Francisquito	Lower reach-soft bottom with stabilizers	Upper reach-soft bottom with stabilizers
Violin Canyon	Lower reach-concrete channel	Upper reach-concrete channel with debris control.
Castaic Creek	Below I-5 Freeway-soft bottom with protective levee	Above I-5 Freeway-soft bottom with stabilizers or concrete channel.

3. SEDIMENT PRODUCTION AND DELIVERY

Los Angeles Basin (see Figure 3.1), Santa Clara River Basin (see Figure 3.2), and Antelope Valley (see Figure 3.3) are divided into zones that yield similar volumes of sediment under similar conditions. These are called "Debris"[1] (sediment) Potential Area (DPA) zones.

Sediment production from a watershed is a rate at which sediment passes a particular point, usually expressed as cubic yards per square mile per storm. The sediment production is dependent upon many factors such as: rainfall intensity, geology, soil type, vegetative coverage, runoff, and watershed slope.

Design Debris Event (DDE) is defined as that quantity of sediment produced by a saturated watershed significantly recovered from a burn (after four years) as a result of 24-hour rainfall amounts with a recurrence interval of once in 50 years. The concept of Debris (sediment) Potential Area (DPA) zones and Debris Production (DP) curves for determining watershed sediment production was introduced after the 1938 storms. Each DP curve and DPA zone represents particular types of geologic, topographic, vegetative, and rainfall features. These curves have been modified several times since inception of the concept.

A rate of 120,000 cubic yards per square mile per storm has been established as the design debris event for a one square-mile drainage area in DPA 1 zone. This rate is used as a design value for debris basins in areasof high relief and granitic formations characterizing the San Gabriel Mountains and Verdugo Hills. Other mountain areas in the County have been assigned relatively lower sediment potentials based on historical data and differences in topography, geology, and rainfall. Studies of sediment flow records indicate that areas less than one square-mile are expected to produce a higher rate of sediment production and areas greater than one square mile a lower rate.

In designing sediment retention facilities, use the DP curves to determine sediment production of an undeveloped watershed, see Section B-1. For a more complex watershed that has multiple DPA zones and/or has been partially developed, see Section B-2 through B-4.

In cases where slides or unstable slopes are found in the watershed, additional capacity may be required in the sediment retention facility as determined by a registered geologist and approved by the Department's Materials Engineering Division.

[1] The term "debris" is used in this manual to be consistent with past practice but it means sediment.

A. SEDIMENT PRODUCTION ZONES AND CURVES

The Los Angeles Basin has five sediment production curves, the Santa Clara River Basin has four curves, and the Antelope Valley has eight. See debris production curves in Appendix P.

The use of DPA 7 in the Los Angeles Basin is limited to undeveloped areas with slopes less than 20%.

B. SEDIMENT DELIVERY

The following sections show the procedures to determine sediment production from watersheds with different characteristics. Sediment production is used for sizing and selection of sediment control/conveyance structures. (See Example 1 in Appendix R.)

B-1. Undeveloped Watershed

Use the following procedure to determine sediment production at the outlet of an undeveloped watershed which completely fallswithin the boundaries of one Debris Potential Area (DPA) zone:

(1) Identify the DPA zone from the maps in Appendix A.

(2) Determine the drainage area (A) in square miles.

(3) Determine the Debris Production Rate (DPR) from curves in Appendix P-1, 2, or 3, corresponding to the DPA zone and the drainage area found in steps (1) and (2) above. For areas smaller than 0.1 square mile, use the same DPR for 0.1 square mile.

(4) Calculate the total Debris Production (DP) by multiplying the Debris Production Rate (DPR), from step (3), by the drainage area (A), from step (2). The equations are as follows:

For a single watershed:

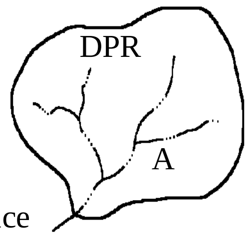


Figure 3.4

$$DP = DPR_{(A)} \times A \qquad (3.1)$$

For multiple watersheds having a common outlet:

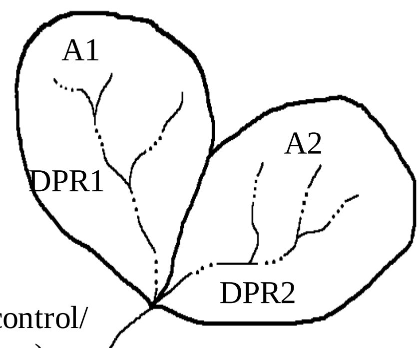


Figure 3.5

$$DP = (DPR_{1(A_1)} \times A_1) + (DPR_{2(A_2)} \times A_2) \qquad (3.2)$$

where: DP = Debris production, in cubic yards

$DPR_{i\,(Ai)}$ = Debris production rate based on area A_i in DPA zone i, in cubic yards per square mile

A_i = Drainage area, in square miles.

B-2. Partially Developed Watershed

Developed areas such as house/commercial pads, paved streets and parking areas, and maintained permanently landscaped areas that are not subject to burning (e.g. golf courses, cemeteries, ...) are considered non-debris producing. Other features such as a geologically non-erosive rock may be considered non-debris producing if supported by a geologic report. Use the equation below to calculate the total sediment production:

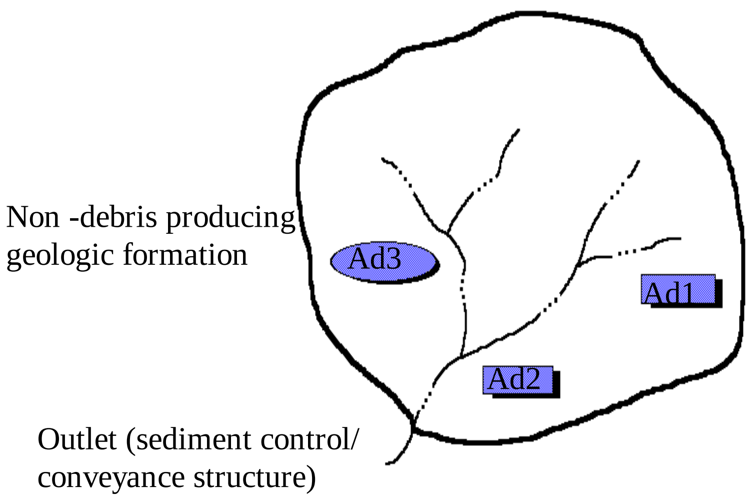


Figure 3.6

$$
\begin{aligned}
DP &= DPR_{(A)} \times A_u \left(\frac{A_u}{A}\right) + DPR_{(A_u)} \times A_u \left(\frac{A_d}{A}\right) \\
A_d &= A_{d_1} + A_{d_2} + A_{d_3} \\
A_u &= A - A_d
\end{aligned}
\qquad (3.3)
$$

where:

DP	=	Debris production, in cubic yards
$DPR_{(A)}$	=	Debris production rate based on the total drainage area, A, in cubic yards per square mile
$DPR_{(Au)}$	=	Debris production rate based on the total undeveloped drainage area, A_u, in cubic yards per square mile
A	=	Total drainage area, including developments, in square miles
A_u	=	Total undeveloped area, in square miles
A_d	=	Total developed area (existing only), in square miles.

B-3. Multiple Debris Production Zones

For an undeveloped watershed in two DPA zones:

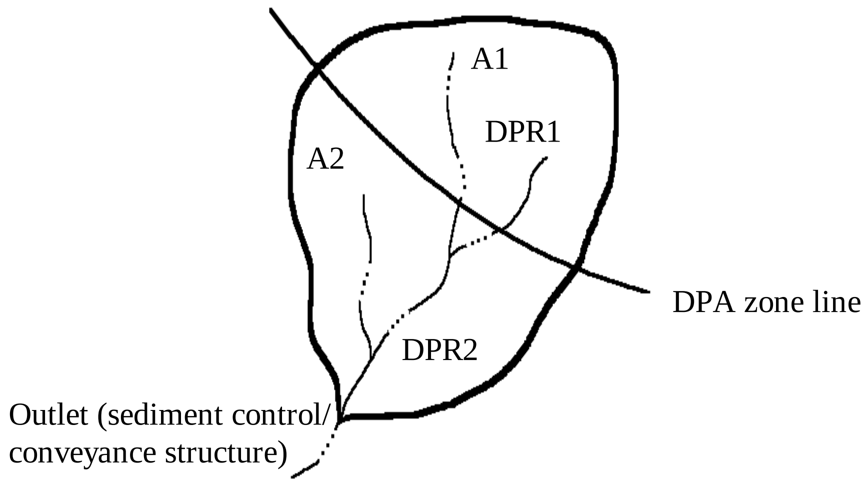


Figure 3.7

$$DP = DPR_{1(A_1+A_2)} \times A_1 \left(\frac{A_1}{A_1+A_2}\right) + DPR_{1(A_1)} \times A_1 \left(\frac{A_2}{A_1+A_2}\right) + DPR_{2(A_1+A_2)} \times A_2 \left(\frac{A_2}{A_1+A_2}\right) + DPR_{2(A_2)} \times A_2 \left(\frac{A_1}{A_1+A_2}\right) \tag{3.4}$$

For a partially developed watershed in two DPA zones:

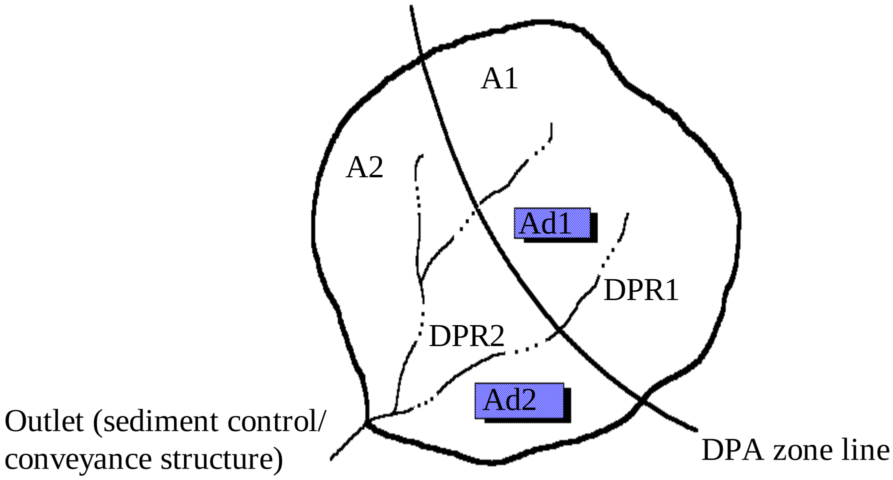


Figure 3.8

$$DP = DPR_{1(A_1+A_2)}\,(A_1-A_{d_1})\left(\frac{A_1-A_{d_1}}{A_1+A_2}\right) + DPR_{1(A_1-A_{d_1})}\,(A_1-A_{d_1})\left(\frac{A_2+A_{d_1}}{A_1+A_2}\right) + DPR_{2(A_1+A_2)}\,(A_2-A_{d_2})\left(\frac{A_2-A_{d_2}}{A_1+A_2}\right) + DPR_{2(A_2-A_{d_2})}\,(A_2-A_{d_2})\left(\frac{A_1+A_{d_2}}{A_1+A_2}\right) \quad (3.5)$$

where: DP = Debris production, in cubic yards

$DPR_{i(Ai)}$ = Debris production rate for drainage area A_i in DPA zone i, in cubic yards per square mile

A_i = Drainage area, in square miles, including development

A_{di} = Developed area in area A_i, in square miles.

B-4. Existing Sediment Control Structure

Use the following procedure to determine sediment production from a watershed partially controlled by an existing sediment control structure that meets the Department standards:

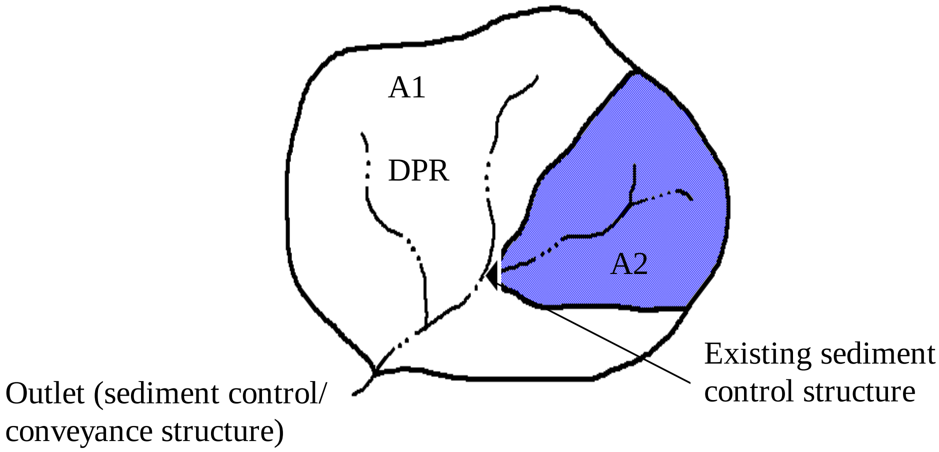


Figure 3.9

Follow steps (1) through (3) in Section B-1. The equation to calculate the total sediment production depends on the condition of the existing sediment control structure:

a) Adequately sized:
b) Undersized:

$$DP \;'\; DPR_{(A_1\%A_2)}\, A_1 \left(\frac{A_1}{A_1\%A_2}\right) \;\%\; DPR_{A_1}\, A_1 \left(\frac{A_2}{A_1\%A_2}\right) \tag{3.6}$$

$$DP \;'\; DPR_{(A_1\%A_2)}\, A_1 \left(\frac{A_1}{A_1\%A_2}\right) \;\%\; DPR_{A_1}\, A_1 \left(\frac{A_2}{A_1\%A_2}\right) \;\%\; DPR_{A_2}\, A_2 \;\&\; C \tag{3.7}$$

where: DP = Debris production, in cubic yards
$DPR_{(Ai)}$ = Debris production rate based on area A_i, in cubic yards per square mile
A_i = Drainage area, in square miles
C = Capacity of sediment control structure, in cubic yards.

C. BULKING AND BULKED FLOW HYDROGRAPH

C-1. Bulking

Bulking is the increase in flow rate due to inclusion of sediment in the flow. This condition applies primarily to mountain areas subject to wildfires that destroy the vegetative cover protecting the soil. It also applies to watersheds in mountain areas with loose surface material that is likely to produce sediment.

The peak bulking factor curves in Appendix P show the proportion of the bulked flow rate to burned flow rate during the peak of the flood hydrograph or to the clear flow rate if the watershed has no potential to burn. These curves are used to design channels in a sediment producing area where a debris basin does not exist. The use of these curves is illustrated in Appendix R (Example 1).

The procedures for determining bulking factors for watersheds with different characteristics are similar to the procedures for determining sediment production explained in Section B. To determine bulked Q, use the equation listed below for the appropriate case.

For a single undeveloped watershed (see Figure 3.4):

$$Q_B = BF_{(A)} \times Q_{(A)} \tag{3.8}$$

For multiple undeveloped watersheds having a common outlet (see Figure 3.5):

$$Q_B = BF_{1(A_1)} \times \left(\frac{Q\,A_1}{A_1 + A_2} \right) + BF_{2\,(A_2)} \times \left(\frac{Q\,A_2}{A_1 + A_2} \right) \tag{3.9}$$

For a partially developed watershed (see Figure 3.6):

$$Q_B = BF_{(A)} \times \left(\frac{Q_{(A)}\,A_u}{A} \right) \left(\frac{A_u}{A} \right) + BF_{(A_u)} \times \left(\frac{Q_{(A)}\,A_u}{A} \right) \left(\frac{A_d}{A} \right) + \left(\frac{Q_{(A)}\,A_d}{A} \right) \tag{3.10}$$

For a watershed with multiple debris production zones (see Figure 3.7):

$$Q_B = BF_{1(A_1+A_2)} \times \left(\frac{Q\,A_1}{A_1+A_2}\right)\left(\frac{A_1}{A_1+A_2}\right) + BF_{1(A_1)} \times \left(\frac{Q\,A_1}{A_1+A_2}\right)\left(\frac{A_2}{A_1+A_2}\right) +$$
$$BF_{2(A_1+A_2)} \times \left(\frac{Q\,A_2}{A_1+A_2}\right)\left(\frac{A_2}{A_1+A_2}\right) + BF_{2(A_2)} \times \left(\frac{Q\,A_2}{A_1+A_2}\right)\left(\frac{A_1}{A_1+A_2}\right) \tag{3.11}$$

where $Q = Q_{A_1+A_2}$

For a partially developed watershed in multiple DPA zones (see Figure 3.8):

$$Q_B = BF_{1(A_1+A_2)} \left(\frac{Q\,(A_1-A_{d_1})}{A_1+A_2}\right)\left(\frac{A_1-A_{d_1}}{A_1+A_2}\right) +$$
$$BF_{1(A_1-A_{d_1})} \left(\frac{Q\,(A_1-A_{d_1})}{A_1+A_2}\right)\left(\frac{A_2+A_{d_1}}{A_1+A_2}\right) + \left(\frac{Q\,(A_{d_1})}{A_1+A_2}\right) +$$
$$BF_{2(A_1+A_2)} \left(\frac{Q\,(A_2-A_{d_2})}{A_1+A_2}\right)\left(\frac{A_2-A_{d_2}}{A_1+A_2}\right) +$$
$$BF_{2(A_2-A_{d_2})} \left(\frac{Q\,(A_2-A_{d_2})}{A_1+A_2}\right)\left(\frac{A_1+A_{d_2}}{A_1+A_2}\right) + \left(\frac{Q\,(A_{d_2})}{A_1+A_2}\right) \tag{3.12}$$

For a watershed with an adequately sized, existing control structure (see Figure 3.9):

$$Q_B = BF_{(A_1+A_2)} \left(\frac{Q\,A_1}{A_1+A_2}\right)\left(\frac{A_1}{A_1+A_2}\right) + BF_{(A_1)} \left(\frac{Q\,A_1}{A_1+A_2}\right)\left(\frac{A_2}{A_1+A_2}\right) \tag{3.13}$$

For a watershed with an undersized, existing control structure (see Figure 3.9):

$$Q_B = BF_{(A_1+A_2)} \left(\frac{Q A_1}{A_1+A_2}\right) \left(\frac{A_1}{A_1+A_2}\right) + BF_{(A_1)} \left(\frac{Q A_1}{A_1+A_2}\right) \left(\frac{A_2}{A_1+A_2}\right) +$$
$$BF_{(A_2)} \times \left(\frac{Q A_2}{A_1+A_2}\right) \tag{3.14}$$

where:
Q = Clear or burned discharge, in cfs
Q_B = Bulked or burned and bulked discharge, in cfs
$BF_{(Ai)}$ = Bulking factor based on area A_i
A_i = Drainage area, in square miles
A_u = Total undeveloped area, in square miles
A_d = Total developed area, in square miles.

The Los Angeles Basin has a set of five bulking factor curves as shown in Appendix P-4. Appendix P-5 and P-6 show the bulking factors for the Santa Clara River Basin and the Antelope Valley area.

C-2. Bulked Flow Hydrograph

Bulked flow hydrograph is used for fluvialanalysis and flood regulation studies. The bulked flow discharge can be obtained from the following equation:

$$Q_b = Q_s + Q_w \tag{3.15}$$

where:
Q_b = Bulked flow discharge
Q_s = Sediment discharge
Q_w = Water discharge (clear or burned).

This equation assumes that the peak of the sediment hydrograph coincides with the peak of the clear or burned water hydrograph.

To distribute the total design sediment volume (as described in Section B) throughout a hydrograph, the Department uses the following equation:

$$Q_s = a \times (Q_w)^n \tag{3.16}$$

where: a = Bulking constant (fixed throughout the hydrograph)
n = Bulking exponent (fixed throughout the hydrograph).

Assume values of n to solve for a. The total sediment volume determined from the computed sediment hydrograph is then compared with the total volume obtained from the sediment production curves in Appendix P-1, 2, or 3. The value of n is then adjusted until the total volume under the sediment hydrograph is approximately equal to the total volume obtained from Appendix P-1, 2, or 3.

Consult with the Department for additional guidelines if analysis of this type is needed.

D. <u>GENERAL FORM EQUATIONS - Debris Production Rates & Bulking Factors</u>

These equations are the general form of the equations in Sections B and C and can be used for multiple DPA zones. The number to the right of each equation corresponds to the number of the equation in Section B or C.

$$DP = DPR_{(A)} \times A \qquad (3.1g)$$

$$DP = \sum (DPR_{i(A_i)} \times A_i) \qquad (3.2g)$$

where: DP = Debris production, in cubic yards
$DPR_{i\,(Ai)}$ = Debris production rate based on area A_i in DPA zone i, in cubic yards per square mile
A_i = Drainage area, in square miles.

$$\begin{aligned} DP &= DPR_{(A)} \times A_u \left(\frac{A_u}{A}\right) + DPR_{(A_u)} \times A_u \left(\frac{A_d}{A}\right) \\ A_d &= \sum (A_{d_1} + A_{d_2} + A_{d_3} + \ldots + A_{d_n}) \\ A_u &= A - A_d \end{aligned} \qquad (3.3g)$$

where: DP = Debris production, in cubic yards
$DPR_{(A)}$ = Debris production rate based on the total drainage area, A, in cubic yards per square mile
$DPR_{(Au)}$ = Debris production rate based on the total undeveloped drainage area, A_u, in cubic yards per square mile
A = Total drainage area, including developments, in square miles
A_u = Total undeveloped area, in square miles
A_d = Total developed area (existing only), in square miles.

$$DP = \sum \left[DPR_{i(A)} \times A_i \left(\frac{A_i}{A}\right) + DPR_{i(A_i)} \times A_i \left(\frac{A-A_i}{A}\right) \right] \qquad (3.4g)$$

$$DP = \sum \left[DPR_{i(A)} \, (A_i - A_{d_i}) \left(\frac{A_i - A_{d_i}}{A} \right) + DPR_{i(A_i - A_{d_i})} \, (A_i - A_{d_i}) \left(\frac{(A - A_i) + A_{d_i}}{A} \right) \right] \tag{3.5g}$$

where: DP = Debris production, in cubic yards
$DPR_{i(Ai)}$ = Debris production rate for drainage area A_i in DPA zone i, in cubic yards per square mile
A = Total drainage area, in square miles
A_i = Drainage area, in square miles, including development
A_{di} = Developed area, in area A_i, in square miles.

$$DP = \sum \left[DPR_{i(A)} \, (A_i - A_{c_i}) \left(\frac{A_i - A_{c_i}}{A} \right) + DPR_{i(A_i - A_{c_i})} \, (A_i - A_{c_i}) \left(\frac{(A - A_i) + A_{c_i}}{A} \right) \right] \tag{3.6g}$$

$$DP = \sum \left[DPR_{i(A)} (A_i - A_{c_i}) \left(\frac{A_i - A_{c_i}}{A} \right) + DPR_{i(A_i - A_{c_i})} (A_i - A_{c_i}) \left(\frac{(A - A_i) + A_{c_i}}{A} \right) + DPR_{(A_{ci})} \; (A_{ci}) - C_i \right] \tag{3.7g}$$

where: DP = Debris production, in cubic yards
$DPR_{(Ai)}$ = Debris production rate based on area A_i, in cubic yards per square mile
A = Total drainage area, in square miles
A_i = Drainage area, in square miles
A_{ci} = Controlled drainage area within A_i, in square miles
C_i = Capacity of sediment control structure, in cubic yards.

$$Q_B = BF_{(A)} \times Q \tag{3.8g}$$

$$Q_B = \sum \left[BF_{i(A_i)} \times \left(\frac{Q\,A_i}{A} \right) \right] \tag{3.9g}$$

$$Q_B = BF_{(A)} \times \left(\frac{Q\,A_u}{A} \right) \left(\frac{A_u}{A} \right) + BF_{(A_u)} \times \left(\frac{Q\,A_u}{A} \right) \left(\frac{A_d}{A} \right) + \left(\frac{Q\,A_d}{A} \right) \tag{3.10g}$$

$$Q_B = \sum \left[BF_{i(A)} \times \left(\frac{Q\,A_i}{A} \right) \left(\frac{A_i}{A} \right) + BF_{i(A_i)} \times \left(\frac{Q\,A_i}{A} \right) \left(\frac{(A - A_i)}{A} \right) \right] \tag{3.11g}$$

$$Q_B = \sum \quad BF_{i(A)} \left(\frac{Q\,(A_i - A_{d_i})}{A} \right) \left(\frac{A_i - A_{d_i}}{A} \right) + \\ BF_{i(A_i - A_{d_i})} \left(\frac{Q\,(A_i - A_{d_i})}{A} \right) \left(\frac{(A - A_i) + A_{d_i}}{A} \right) + \left(\frac{Q\,(A_{d_i})}{A} \right) \tag{3.12g}$$

$$Q_B = \sum \quad BF_{i(A)} \left(\frac{Q\,(A_i - A_{c_i})}{A} \right) \left(\frac{A_i - A_{c_i}}{A} \right) + \\ BF_{i(A_i - A_{c_i})} \left(\frac{Q\,(A_i - A_{c_i})}{A} \right) \left(\frac{(A - A_i) + A_{c_i}}{A} \right) + \left(\frac{Q\,(A_{c_i})}{A} \right) \tag{3.13g}$$

$$Q_B = \sum BF_{i(A)} \left(\frac{Q\,(A_i - A_{c_i})}{A} \right) \left(\frac{A_i - A_{c_i}}{A} \right) +$$

$$BF_{i(A_i - A_{c_i})} \left(\frac{Q\,(A_i - A_{c_i})}{A} \right) \left(\frac{(A - A_i) + A_{c_i}}{A} \right) + \left(\frac{Q\,(A_{c_i})}{A} \right) +$$

$$BF_{(A_{c_i})} \left(\frac{Q\,(A_{c_i})}{A} \right) \tag{3.14g}$$

where:	Q	=	Total clear or burned discharge, in cfs
	Q_B	=	Bulked or burned and bulked discharge, in cfs
	$BF_{(Ai)}$	=	Bulking factor based on area A_i
	A	=	Total drainage area, in square miles
	A_i	=	Drainage area, in square miles
	A_u	=	Total undeveloped area, in square miles
	A_d	=	Total developed area, in square miles.

4. SEDIMENT CONTROL

This Section discusses the type of structure acceptable to the Department for sediment control. The type of structure depends on the volume of sediment computed to be delivered to the site. This, in turn, depends on the Debris (sediment) Potential Area (DPA) zone for the particular watershed. The following table is used to determine the type of structure. See Section 3 for methods of computing the sediment production volume.

	Type of Structure	
Total Sediment Production (cubic yards)	DPA zone 1-4 requirement	DPA zone 5-11 requirement
20,000 or greater	Debris Basin	Debris Basin
5,000 to 19,999	Debris Basin	Elevated Inlet
1,000 to 4,999	Debris Basin or Elevated Inlet *	Desilting Inlet
250 to 999	Desilting Inlet *	Inlet with bulked flow drain
less than 250	Inlet* with bulked flow drain	Inlet with bulked flow drain

* The use of elevated or desilting inlets and bulked flow drains in DPA zones 1 through 4 will only be approved by the Department in special circumstances. The reason being that the steepness of the watershed, presence of boulders, and higher sediment and mudflow potential result in a greater risk of plugging the storm drain and damaging the desilting wall.

Table 4.1

Where sediment production is less than 250 cubic yards, sediment control is generally not needed. Design the conveying storm drain following the closed conduit bulked flow design criteria listed in Section 5.D-2.

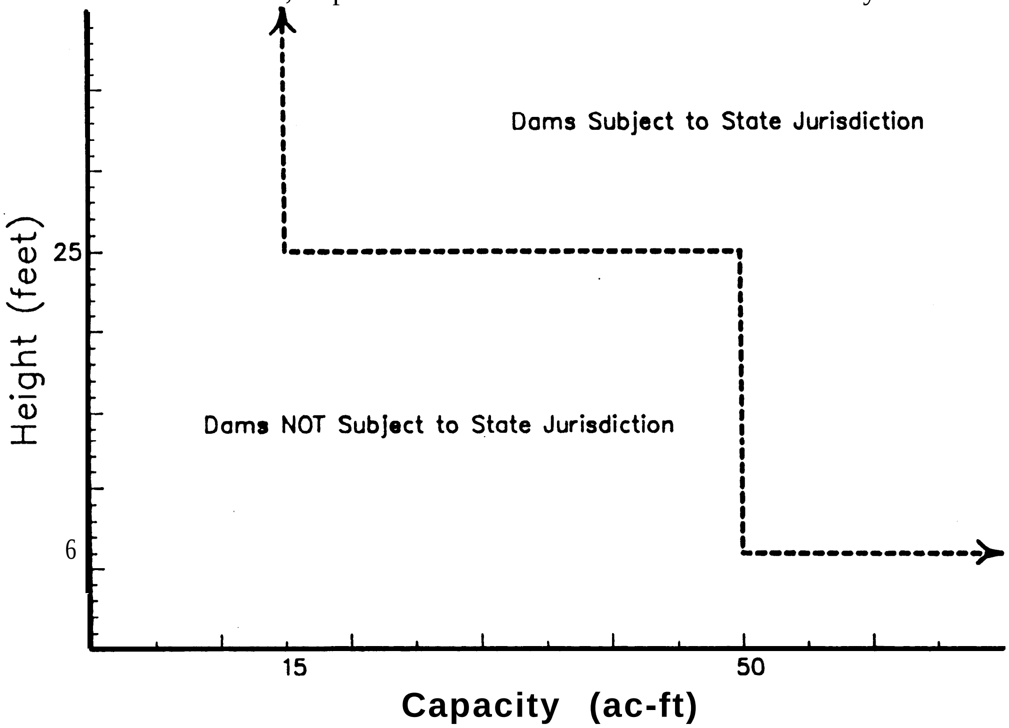
As stated in the State Water Code, Division 3, Section 6000-6452, certain dams are under State jurisdiction (refer to Figure 4.1). The State may have additional requirements for the design of the facility.

A. GENERAL DESIGN CONSIDERATIONS

A-1. Location and Alignment

Locate all sediment retaining facilities in the existing watercourse. Align dams perpendicular to the original flow paths (see Figure 4.2(a)). In order to insure maximum capacity, place the longer dimension of the basin along the flow line of the water course. If this distance is short in relation to the width, the intended capacity may not be attained.

DESIGN LIMITATIONS AND JURISDICTION OF DAMS IN CALIFORNIA
Reference: Statutes and Regulations Pertaining to Supervision of Dams and Reservoirs, 1970 by State of California, Department of Water Resources Division of Safety of Dams



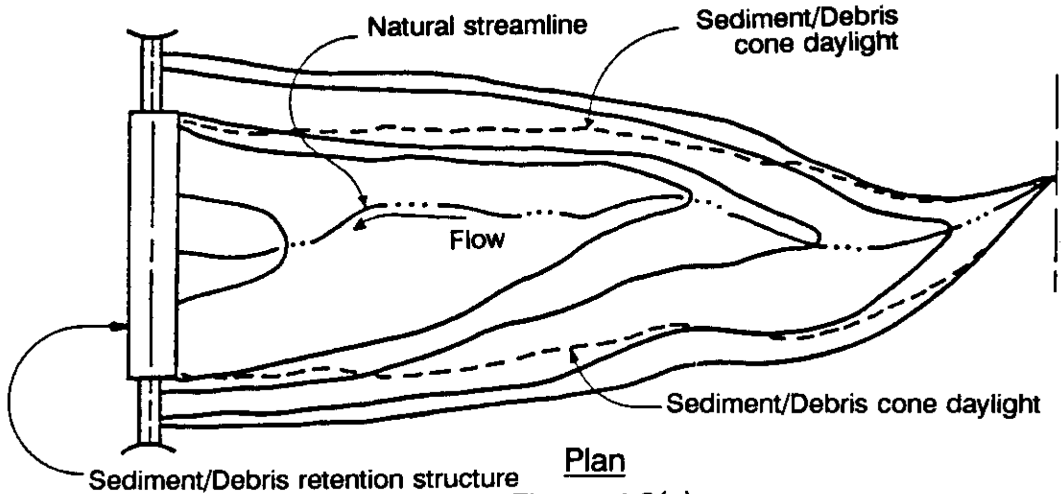
NOTE: This information was current to the best of our knowledge at the time of publication, but the user should verify the most current criteria to be used.

FIGURE 4.1

A-2. Cone Slope

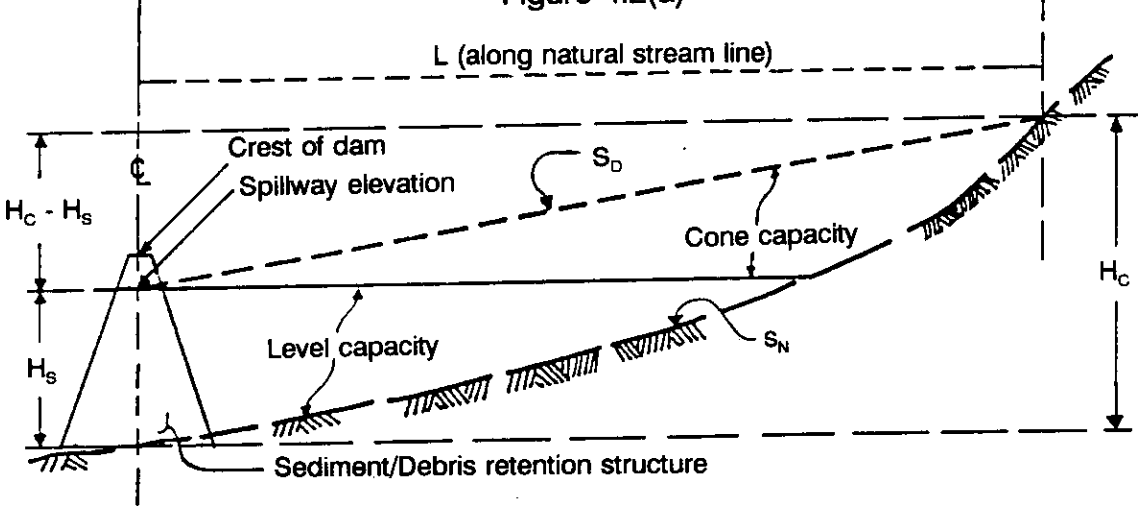
Sediment-laden flood flow, when reaching a sediment retaining facility, deposits the sediment up to spillway elevation and forms a delta or cone sloping upward from spillway. For design purposes, this cone may contain up to, but no more than, one-half the capacity of the basin; this is called cone capacity (see Figure 4.2(b)). The slope of the cone (S_D) is taken as one half of the average natural slope of the stream (S_N). The cone slope (S_D) should not exceed five percent (0.05).

In cases where the stream branches as it moves upstream from the debris dam, cone calculations are to be made along the individual profile lines of each branch. Depending upon the stream configuration, the profiles may



Plan

Figure 4.2(a)



Profile

Figure 4.2(b)

H_S = Height of structure.

H_C = Height of cone = $2H_S$.

S_N = Natural slope = $\frac{H_C}{L}$, where L = length along streamline.

S_D = Sediment / Debris cone slope = 0.5 S_N, where $S_D \leq 5$ percent.

DEFINITION OF SEDIMENT/DEBRIS BASIN CAPACITY PARAMETERS

FIGURE 4.2

branch from either the spillway crest or perhaps upstream of the crest. Hence, it is possible to have two different cone slopes. In these cases, the cone lines drawn perpendicular to the profile lines will intersect showing the configuration of the final cone surface (see Figure 4.3).

A-3. Level Capacity

The basin capacity up to the spillway elevation is called the "Level Capacity" (see Figure 4.2(b)). Level capacity shall be at least one-half the capacity of the basin.

A-4. Momentum Overflow

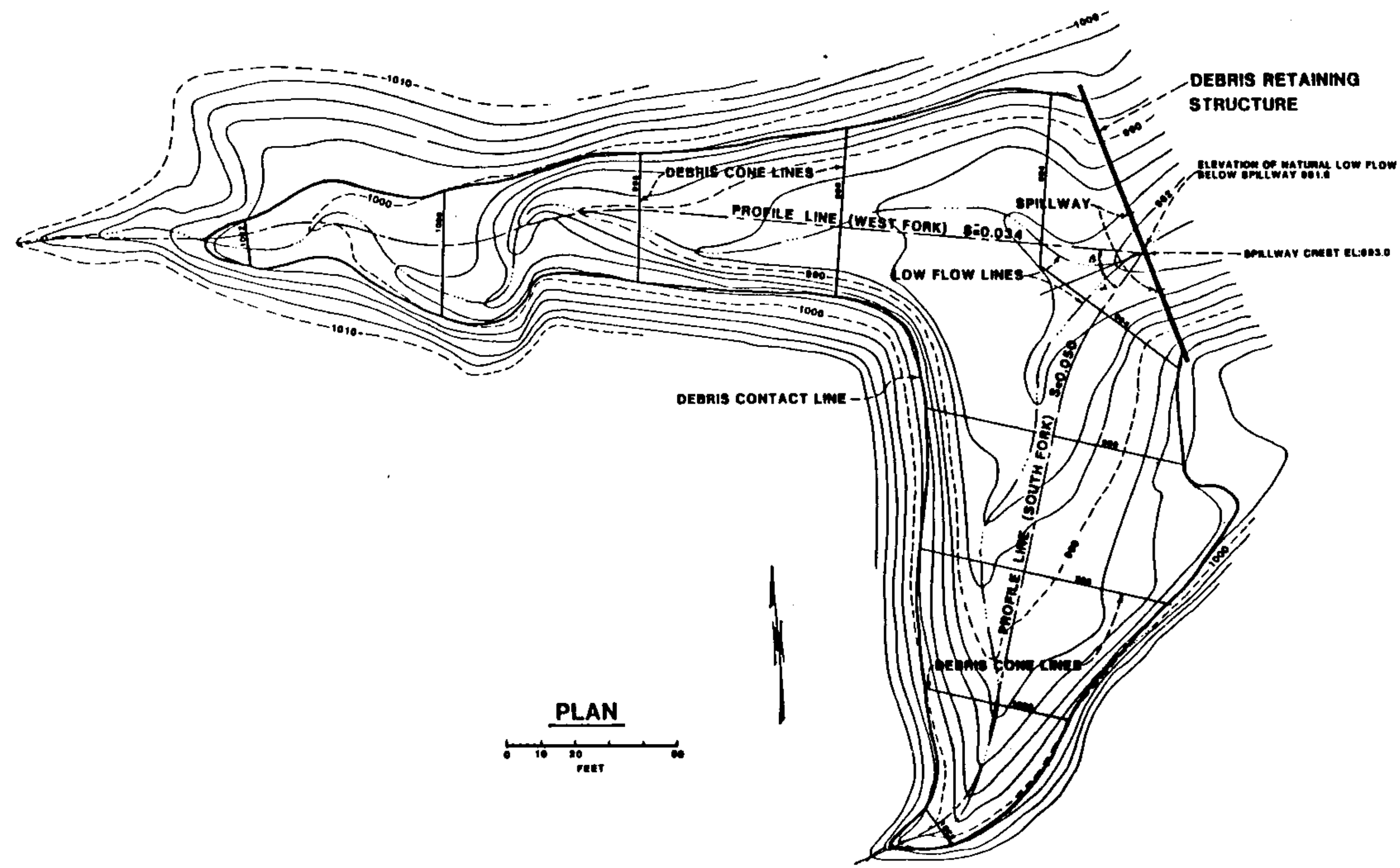
In the 1969 and the 1978 storms, in some locations there were unexpected events that occurred where significant amounts of sediment overflowed the spillway, and in some cases the dam, before the basin was full. This event has been referred to as "Momentum Overflow."

It is believed that there is a broad range of contributing factors to this phenomenon. Some of the important factors are: rainfall amounts and intensity, watershed size, slope shape and condition (burned or unburned), soil composition, Debris Potential Area zone, shape of debris basin, total versus cone capacity of the basin, slope of upstream face of the dam, and spillway location or combinations of these factors.

The likelihood of "Momentum Overflow" is reduced if the following is adhered to in the design of the sediment retaining facility:

- The cone slope is limited to a maximum of five percent.

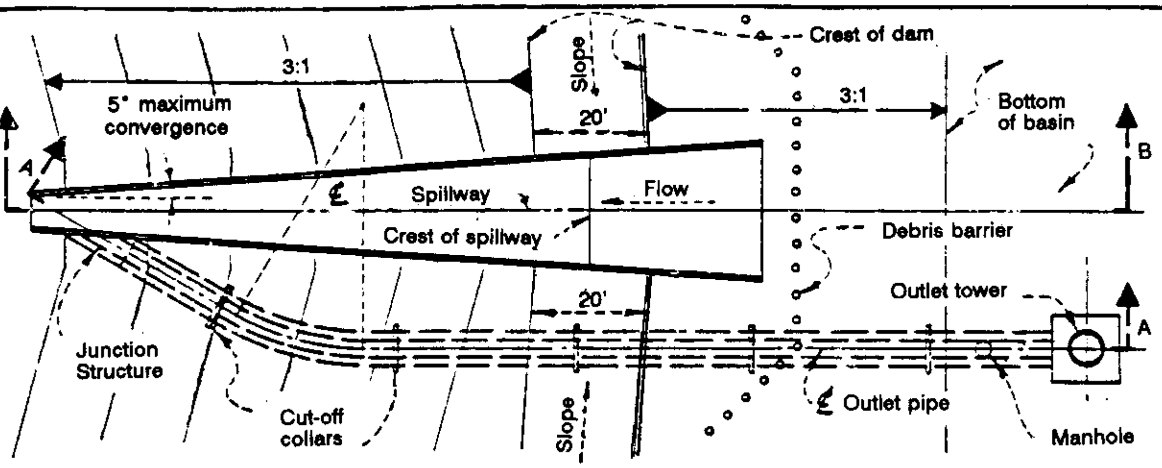
- The level capacity is large enough to accommodate at least 50 percent of the debris event.



DEBRIS SLOPE CALCULATION

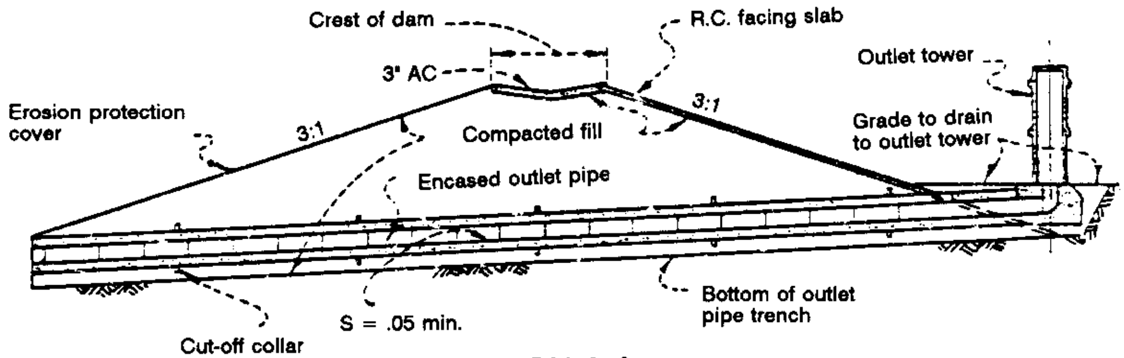
FIGURE 4.3

Los Angeles County Department Of Public Works
Debris Slope Calculation And Representation On Plan

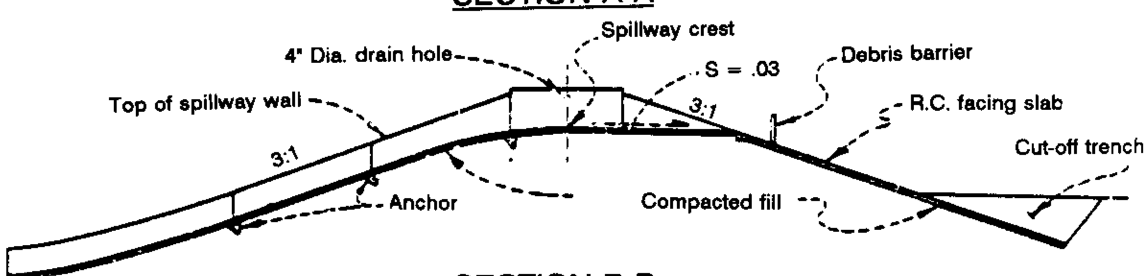


PLAN

TYPICAL SPILLWAY AND OUTLET WORKS



SECTION A-A



SECTION B-B

TYPICAL DEBRIS BASIN

FIGURE 4.4

B. STANDARD SEDIMENT CONTROL METHODS

B-1. Debris Basin

The Department's Debris Dams and Basins Design Manual provides the specific design criteria for a debris basin. See Figure 4.4 for a typical debris basin. Exceptions are listed in Table 4.2. (See also Appendix page R-4 for an example.)

B-2. Elevated Inlet

Elevated inlets can be used if the conditions comply with the conditions for an elevated inlet indicated in Table 4.1. The design concept for this inlet must be approved by the Department prior to proceeding to final plans.

The design criteria for elevated inlets are listed in Table 4.2 and a typical elevated inlet is shown in Figure 4.5.

If for any reason an elevated inlet cannot meet the above requirements, then a debris basin is required.

B-3. Desilting Inlet

Desilting inlets can be used if the conditions comply with the conditions for a desilting inlet indicated in Table 4.1. The design concept for this inlet must be approved by the Department prior to proceeding to final plans.

The design criteria for desilting inlets are listed in Table 4.2 and a typical desilting inlet is shown in Figure 4.6.

If a desilting inlet cannot meet the above requirements, then an elevated inlet or better is required.

Under certain favorable conditions, watersheds in DPA 5 through 11 and producing less than 1000 cubic yards of sediment can be considered for a sediment carrying conduit. The design concept must be approved by the Department prior to proceeding to final plans. See also Table 4.2 and Section 5.D-2.

Table 4.2

<table>
<tr><th></th><th>Debris Basin[1]</th><th>Elevated Inlet
See Figure 4.5</th><th>Desilting Inlet
See Figure 4.6</th></tr>
<tr><td>General Location</td><td></td><td colspan="2">Locate both facilities such that should an overflow occur a street or other safe path is available to convey the water and sediment.</td></tr>
<tr><td>Horizontal alignment</td><td colspan="3">Locate in the original watercourse where the dam is perpendicular to the flow path (see Figure 4.2(a)). Longer dimension of the basin shall fall along the flow line.</td></tr>
<tr><td>Outlet Tower and Conduit</td><td>Refer to the section on Outlet Works in the Department's Debris Dams and Basins Design Manual.</td><td>A standard concrete outlet tower and conduit is required (see the Debris Dams and Basin Design Manual), except in phased upstream development where corrugated metal pipe (CMP) tower with a concrete base may be substituted.[2]</td><td>A corrugated metal pipe outlet tower and pipe is required upstream of the desilting wall.</td></tr>
<tr><td>Gage Boards</td><td>Gage boards are required on basins under State Jurisdiction. Sediment lines painted on towers, marking from the lowest port invert suffice for all others. See the section on Gage Board Pipe Support in the Department's Debris Dams and Basins Design Manual.</td><td colspan="2">Gage boards or sediment lines painted on towers, marking from the lowest port invert can be used.</td></tr>
<tr><td>Earth Embankment</td><td>Upstream and downstream embankment slopes less than or equal to 3H:1V. Steeper slopes require complete geotechnical stability analysis. Also refer to the section on Earthen Dam Design in the Department's Debris Dams and Basins Design Manual.</td><td>Maximum berm slope is 3H:1V. Steeper slopes require complete geotechnical stability analysis. Also refer to the section on Earth Dam Design in the Department's Debris Dams and Basins Design Manual.</td><td>Protect the earth embankment between the desilting wall and the inlet with reinforced concrete facing slab (air placed concrete is acceptable).</td></tr>
<tr><td>Embankment Crest</td><td colspan="3">The top width of the berm over the inlet shall be 20-feet paved 3 inches of asphalt concrete. A berm width of 15-feet may be approved if geological analysis is provided to support the reduction.</td></tr>
<tr><td>Facing Slab</td><td>6-inch concrete or gunite with No. 5 reinforcing steel at 18-inch spacing each way. See section on Earthen Dam Design, Protection for Dam Slopes in the Department's Debris Dams and Basins Design Manual.</td><td colspan="2">A 6-inch thick reinforced concrete facing slab with reinforcing steel (no wire mesh) extending to the canyon wall is required (air placed concrete is acceptable). Provide facing slabs around the basin wall if cut and fill method is used to obtain the capacity.</td></tr>
<tr><td>Trash Barriers</td><td>Refer to the section on Debris Barrier in the Department's Debris Dams and Basins Design Manual.</td><td>A swinging trash rack is required for conduits greater than 48-inches in diameter. A sloping trash rack[3] per LACDPW[4] 3089-0 can be used for smaller conduits. Trash posts spaced at 4-feet or 2/3 the diameter of the conduit, whichever is smaller, are also required at all elevated inlets.</td><td>A sloping trash rack per LACDPW 3089-0 and trash posts spaced at 2/3 the diameter of the conduit are required.</td></tr>
<tr><td>Access Roads</td><td>Access roads with 12 ft wide paving (3-inch asphalt concrete on 4-inch crushed aggregate base) within a 15-ft easement with minimum radius of 40 feet can be used for structures with capacity less than 20,000 cubic yards. See section on Access to Dam and Basin in the Department's Debris Dams and Basins Design Manual.</td><td colspan="2">Provide a vehicular access road into the basin at least 12-feet wide within a 15-feet easement, paved with 3 inches of asphalt concrete over 4 inches of crushed aggregate base.</td></tr>
</table>

	Debris Basin[1]	Elevated Inlet See Figure 4.5	Desilting Inlet See Figure 4.6
Access Ramps	Ramps are required. Refer to the section on Access to Dam and Basin in the Department's Debris Dams and Basins Design Manual. Unpaved ramps for slopes less than 10 percent. Paved ramps (3-inch asphalt concrete on 4-inch crushed aggregate base) for slopes greater than 10 percent up to a maximum of 12 percent.		
Fencing	Refer to the section on Fencing in the Department's Debris Dams and Basins Design Manual. Totally secure the basin area and inlet by 5-foot high fencing per APWA[5] standard drawing 600-0.		
Hydraulic Design	Refer to the section on Design of Rectangular Spillway in the Department's Debris Dams and Basins Design Manual.	Base the hydraulic design of inlet and storm drain on requirements stated in the Department's Hydraulic Design Manual.	
Ponding	Refer to the section on Design of Rectangular Spillway in the Department's Debris Dams and Basins Design Manual.	Maximum allowable ponding at the drain shall be 3-feet above soffit of the conduit inlet.	Maximum allowable ponding at the desilting wall shall be 3-feet above soffit of the drain.
Freeboard	Refer to the section on Design of Rectangular Spillway in the Department's Debris Dams and Basins Design Manual.	Minimum freeboard at the inlet is 2-feet above maximum water surface elevation.	
Drain Size	Refer to the section on Design of Rectangular Spillway in the Department's Debris Dams and Basins Design Manual.	Minimum drain size is 36-inch RCP and maximum drain size is 84-inch RCP or equivalent RC Box.	Minimum drain size is 36-inch and maximum drain size is 48-inch RCP or equivalent RC Box.
Inlet Design Capacity	Refer to the section on Design of Rectangular Spillway in the Department's Debris Dams and Basins Design Manual.	Design inlet and storm drain to convey the clear burned flow rate or the fully developed watershed flow rate, whichever is higher.	Design the spillway notch and the inlet to pass the clear burned flow rate or the fully developed watershed flow rate whichever is higher.
Structural Design	Refer to the section on Structural Design in the Department's Debris Dams and Basins Design Manual. Contact Design Division for additional information.		
Sediment Capacity	Refer to the section on Basin Capacity in the Department's Debris Dams and Basins Design Manual.	19,999 cubic yards of sediment is the maximum allowable capacity in DPA 5-11 and 4,999 cubic yards is the maximum allowable capacity in DPA zones 1-4.	4,999 cubic yards of sediment is the maximum allowable capacity in DPA zones 5-11 and 999 cubic yards is the maximum allowable capacity in DPA zones 1-4.
Desilting Wall Height	N/A	N/A	The maximum desilting wall height is 6-feet.
Desilting Wall Design	N/A	N/A	Design the desilting wall to withstand the overflow of the total burned and bulked flow rate.

Table 4.2 (cont.)

Footnotes:

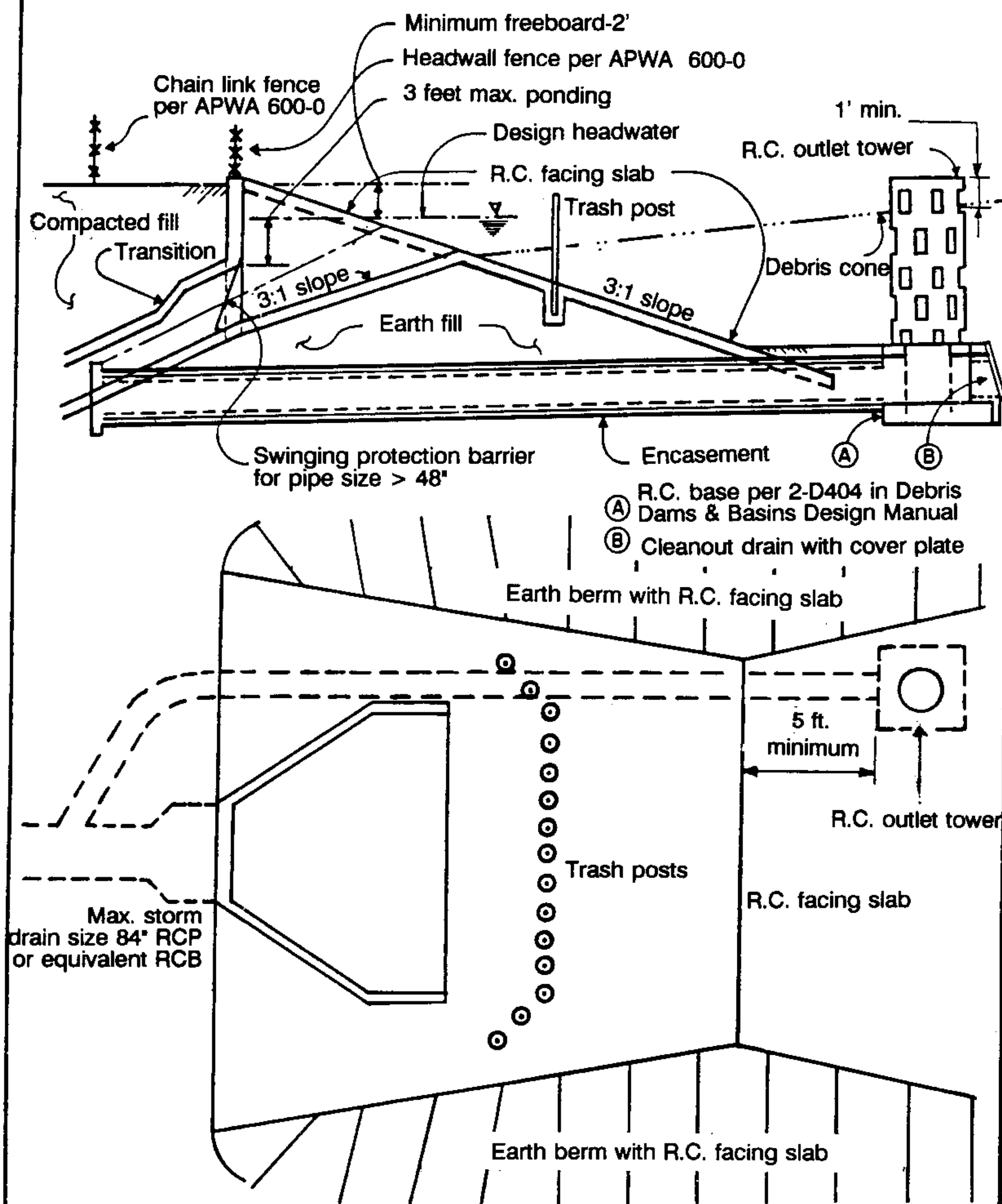
[1] Criteria listed in this table for debris basins amends the criteria given in the Department's Debris Dams and Basins Design Manual.

[2] The tower base can be modified to include a cleanout drain with a cover plate to allow flushing of the conduit. Extend the encasement on the conduit to the junction with the mainline or to a point where a 3H:1V slope originatin from the intersection of the upstream face and the design headwater elevation meets the conduit, whichever is lesser.

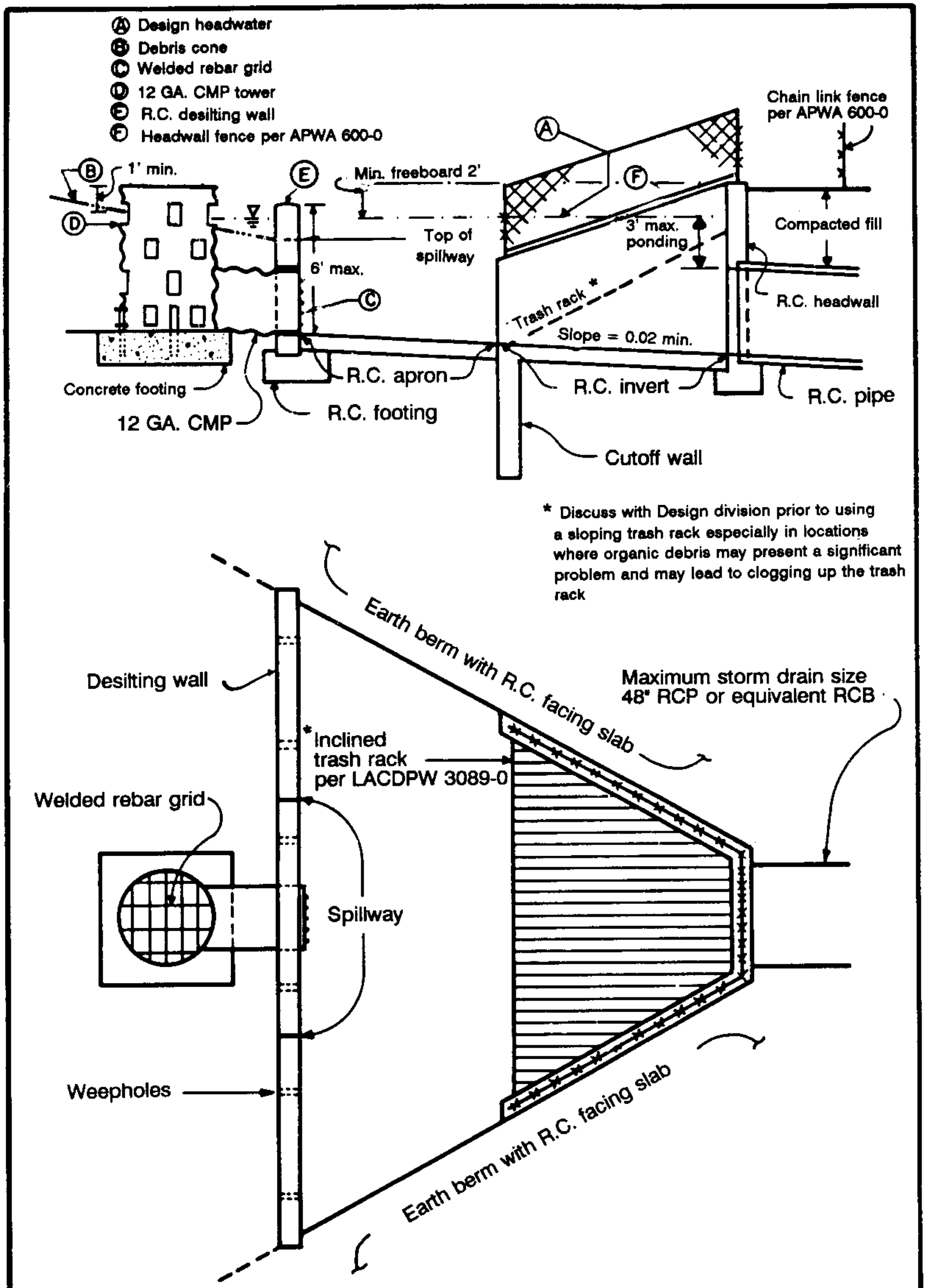
[3] Discuss with Design Division prior to using a sloping trash rack especially in locations where organic debris may present a significant problem and may lead to clogging up the trash rack.

[4] Standard plans designated by an LACDPW number refer to the Department's Standard Plan Manual (1992 Edition).

[5] Standard plans designated by an APWA number refer to the Standard Plans for Public Works Construction Manual by the American Public Works Association, 1985 Edition.



ELEVATED INLET
FIGURE 4.5



*Effective Jan. 1, 1992

DESILTING INLET
FIGURE 4.6

C. OTHER SEDIMENT CONTROL METHODS

Department's preapproval must be obtained at the design concept stage if other methods are proposed. The design criteria for the different alternate sediment control methods are described in the following sections.

C-1. Crib Dam

A crib dam structure was originally developed to stabilize streambeds. However, it can replace an earthen dam in a debris basin where space is limited. The structure is made of a cribbing framework of concrete members and the resulting cells are filled with aggregate. The height is controlled by the allowable stresses in the crib members and is generally not greater than 25 feet.

A design manual for crib dams is currently not available from the Department. Contact the Department's Design Division for design details of the structure. For other design details including outlet works, refer to the Department's Debris Dams and Basins Design Manual.

The following general criteria supplements the design criteria given in the Department's Debris Dams and Basins Design Manual:

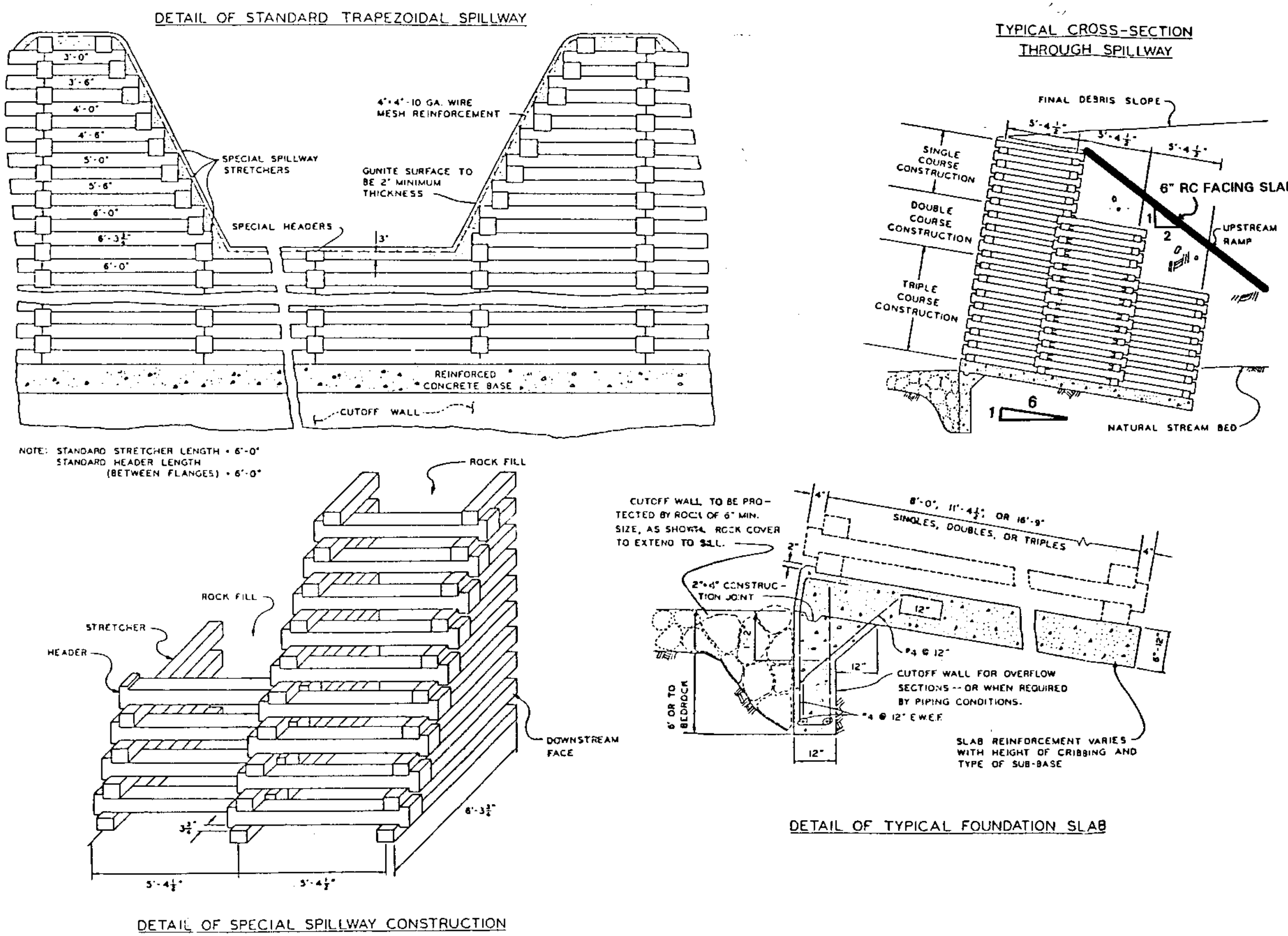
(1) Design the spillway as wide as possible to provide maximum spreading of the flow, and hence reduce stream energy to a minimum.

(2) Cap the portion of the crib structure to be used as a spillway with a reinforced concrete cover.

(3) Place the footing slab and the cribbing of the structure on a 6 horizontal to 1 vertical (6:1) upstream batter (see Figure 4.7).

(4) Construct a six-inch thick reinforced concrete facing slab with a 2 horizontal to 1 vertical (2:1) slope on the upstream face of the dam.

(5) Provide a sill at a distance H+18 feet downstream from the structure to protect the dam from undercutting. Where H is the height of the structure in feet measured from the top of the slab to the water surface at maximum design flow depth.



CRIB DAM

FIGURE 4.7

(6) Construct a reinforced concrete slab or a grouted riprap slab between the sill and structure.

(7) Provide a separate channel headworks downstream of the sill to confine and direct the flow.

(8) Cut-off walls for both the sill and the dam shall be a minimum six feet deep or six inches into bedrock, whichever is less.

C-2. Rail and Timber Structure

Rail and timber structures are primarily used as temporary emergency structures erected below recently burned areas where heavy sediment flows may prevent existing facilities from functioning properly. They are not to be permitted as permanent retention structures. They are generally designed and constructed by Department forces and kept in service until the watershed recovers from the burn.

The height of the structure (H) varies to a maximum 15 feet high with a reinforced concrete slab footing (see Figure 4.8). Refer to the Department's Standard Plans manual (LACDPW 3085-0) for full design details of the structure.

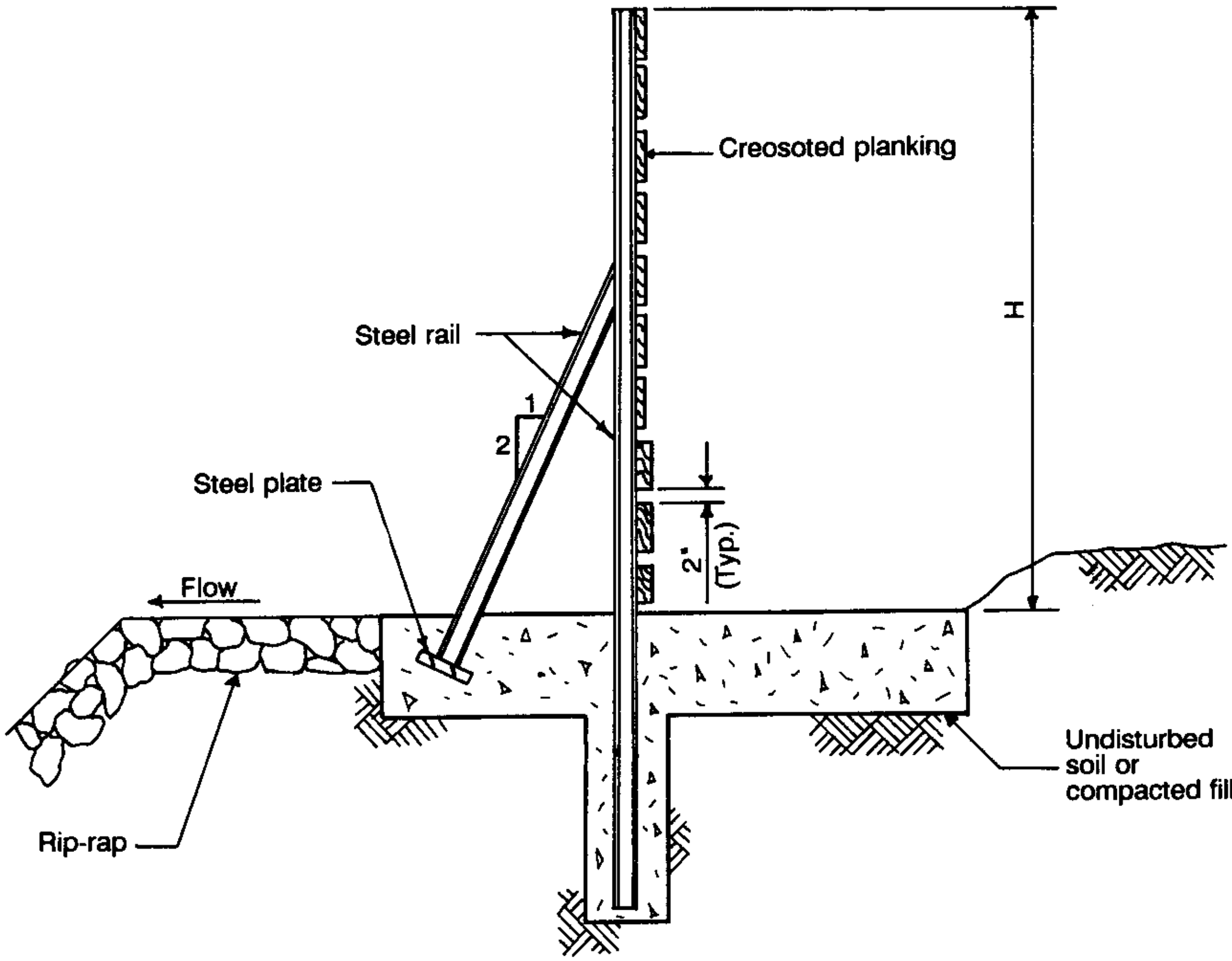
Design the spillway to pass a capital flood Q (burned and bulked).

Provide access into the basin for cleanout purposes. On projects where a road cannot be provided, construct a removable panel in the barrier. For details of the road, refer to the Department's Debris Dams and Basins Design Manual.

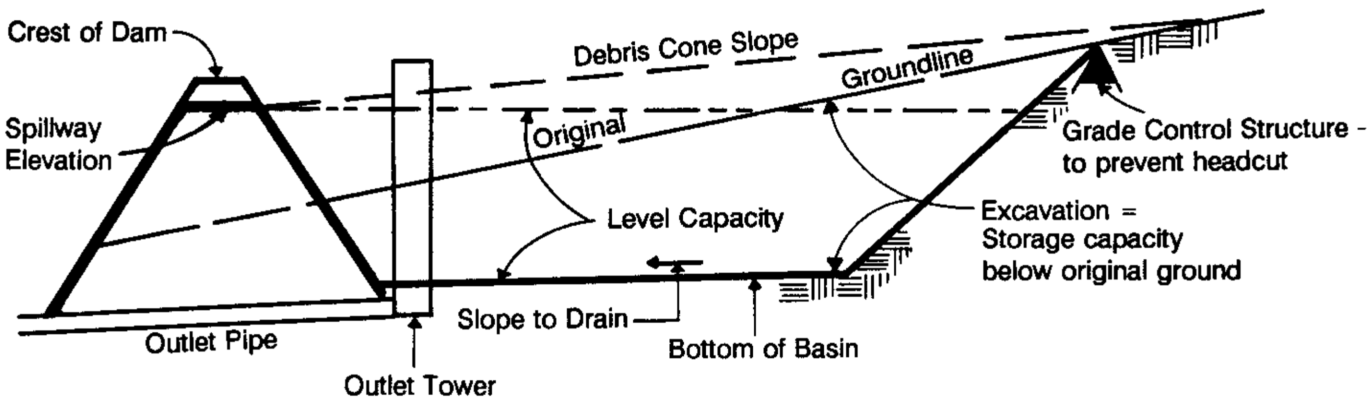
C-3. Pit-type Basin

If a standard basin cannot be designed for the required capacity, a pit-type basin may be considered (see Figure 4.9).

Pit-type basins are generally considered subject to the momentum overflow phenomenon (refer to Section C-4) and, therefore, must be approved by the Department prior to proceeding to final plans.

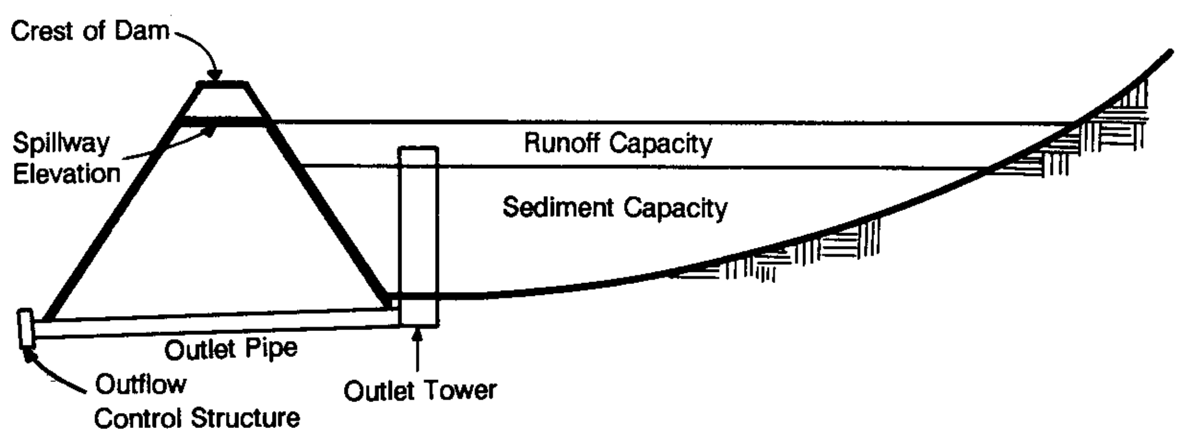


RAIL & TIMBER STRUCTURE
FIGURE 4.8



PIT-TYPE BASIN

FIGURE 4.9



FLOOD RETENTION/DETENTION BASIN

FIGURE 4.10

Not to Scale

The type of outlet structure in a pit-type basin, as in any sediment retention basin, depends on the total sediment production. Refer to Table 4.1 to determine whether a debris basin, an elevated inlet, or a desilting inlet would be required for the design sediment production.

To design the basin capacity, first determine the cone slope then determine the storage ratio. The storage ratio is defined as the ratio of storage capacity below original ground to the total storage capacity (see Figure 4.9).

- If the storage ratio is greater than 0.7, the level capacity shall accommodate 100 percent of the design debris event.
- If the storage ratio is between 0.5 and 0.7, the level capacity shall accommodate at least 80 percent of the design debris event.
- If the storage ratio is below 0.5, the level capacity shall accommodate at least 50 percent of the design debris event.

D. FLOOD RETENTION/DETENTION BASIN

The Department generally requires separate sediment and water retaining facilities. However, in special cases where sediment may deposit in a retention/detention basin, a combined facility may be accepted. Do not proceed with the design, however, until approval is received from the Department.

If the Department accepts the combined facility, then the basin runoff capacity is the difference between inflow versus outflow for the design Q of the facility. Refer to Section 2 for the Department's policy on Level of Flood Protection and to the Hydrology Manual for the method of determining the runoff volume. Sediment storage capacity is equal to the design sediment production of the watershed. Determine the design sediment volume using the sediment production curves in Appendix P. The total capacity of the combined facility is the sum of the volume needed to control runoff and sediment and must be located below spillway elevation (level capacity) (see Figure 4.10).

5. SEDIMENT TRANSPORT

Sediment transport depends on the sediment particle size, shape, specific gravity, and on the flow velocity. Sediment may be transported as bedload or suspended load. Bedload is transported by sliding, rolling, and bouncing over the bed. Suspended load includes the finer portion of the bed material which is intermittently suspended within the flow, and the wash load, which consists of particles too fine to settle to the channel bed.

Some of the more commonly used methods to determine sediment transport capacity are:

- Meyer-Peter, Muller Equation (MPM)
- Einstein Bed Load Equation
- Einstein Suspended Load Methodology
- Colby Methodology

Human activities can disturb the natural conditions of watercourses. Such activities include developments that encroach on the floodplain, construction of sediment trapping facilities, and gravel mining operations.

The Department's general policy for the Santa Clara River and major tributaries is included in Section 2.B. This policy promotes the use of soft-bottom channels to pass sediment through the system where practical. Use debris or sediment control and hard bottom (concrete) channels very sparingly, primarily to be compatible with existing improvements.

The most desirable soft-bottom channel is one that does not degrade or aggrade. This channel is said to be in equilibrium. Developments encroaching on the floodplain reduce the channel width and increase the flow velocity. This in turn increases the sediment transport capacity which leads to invert degradation. Point stabilizers or drop structures may be used to prevent the scour from undermining the levee lining. If a reach is naturally aggrading, channelization can help increase the reach sediment transport capacity to approach the state of equilibrium.

Sediment control facilities and gravel mining operations may significantly decrease the rate of sediment supplied to downstream reaches. This causes the channel bed immediately downstream to erode. A hard-bottom (concrete) channel or soft-bottom channel with a series of drop structures would be necessary to convey the sediment deficient flows.

A. SOFT-BOTTOM CHANNELS WITH LEVEES

Under normal conditions, a sediment balanced soft bottom channel is desired with proper design of invert slope and channel width.

A-1. Conveyance Hydraulics, Erosion, Deposition

Levee failures can be due to general invert scour, bend scour, and/or local scour. Channelization, therefore, needs smooth transitions between varying sections and large radius bends. Also, bridge abutment protection needs to be tied back or blended into the levee lining.

Sediment transport may be estimated through use of procedures listed on page 5-1. For a given channel width, an equilibrium slope can be calculated in a specific reach to satisfy the sediment continuity relationship where sediment transport through the improved reach is equal to the sediment supply into the reach.

$$Q_{S_{in}} = Q_{S_{out}} \tag{5.1}$$

A-2. Scour Protection (Levee Toe-down)

Toe-down or cut-off depth is the depth to which the bank revetment must be extended below grade to prevent undermining as the bed elevation fluctuates. The requirement for toe-down is the total cumulative channel adjustments possible from long-term degradation, general scour, bend scour, local scour, low-flow incisement, and bed forms. (For an example, see Appendix R.)

Use a lower Manning's *n* of 0.025 to estimate scour depth for design of toe-down.

$$Z_{tot} = Z_{deg} + Z_{gs} + Z_{ls} + Z_{bs} + Z_i + \frac{1}{2}h \tag{5.2}$$

where:
- Z_{tot} = Total potential vertical adjustment
- Z_{deg} = Long-term degradation (see (a) below)
- Z_{gs} = General scour (see (b) below)
- Z_{ls} = Local scour (see (c) below)
- Z_{bs} = Bend scour (see (d) below)
- Z_i = Low-flow incisement (see (e) below)
- h = Bed form height (see (f) below).

(a) Long Term Degradation (Z_{deg})

The first step in determining long term degradation is to find the discharge predominantly responsible for channel characteristics. The dominant discharge may be taken as 25% of the Department's Capital flood discharge (Q_{cap}).

Long term degradation (or aggradation) within a particular channel reach may be estimated through use of the equilibrium slope techniques. Equilibrium slope for a channel may be estimated using the following steps:

(1) Identify the supply reach, the reach upstream of the channel that supplies the channel with sediment.

(2) Compute the hydraulic parameters for the supply reach using the dominant discharge.

(3) Using one of the methods from page 5-1 as appropriate for the stream and the hydraulic parameters from step (2), compute the sediment transport rate for the supply reach. This value is known as the sediment supply rate $(Q_{S\ in})$.

(4) Choose an invert slope for the channelized reach, normally milder than the natural slope.

(5) Using that slope, compute the hydraulic parameters for the channel (the transport reach) for the dominant discharge.

(6) Apply the same sediment transport equation used in step (3) to the transport reach and compute the sediment transport rate through the channel $(Q_{S\ out})$.

(7) Compare $Q_{S\ in}$ and $Q_{S\ out}$:
- If equal, then slope chosen in step (4) is the equilibrium slope.
- If $Q_{S\ in} > Q_{S\ out}$, increase slope and repeat steps (5) and (6).
- If $Q_{S\ in} < Q_{S\ out}$, decrease slope and repeat steps (5) and (6).

The curves in Appendix Q-1 (A, B, and C) may be used to estimate the equilibrium slope. These curves show the relationship between the percent increase in velocity resulting from channelization and the corresponding change in invert slope. By subtracting that change from the natural slope you get the equilibrium slope. Each figure consists of four curves to account for various reductions in sediment supply that can result from sediment trapping facilities or gravel mining operations.

When using the curves in Appendix Q-1, compute the percent increase in velocity using the Department's Capital Flood discharge *(Q_{cap})*, and 25% of Q_{cap}. Use the higher percent increase in velocity to determine the equilibrium slope.

Application of the equilibrium slope calculations requires the identification of a suitable point from which the computed equilibrium slope pivots. If natural geological controls such as rock outcroppings or man-made grade control structures exist, these features can serve as pivot points. For a given reach with such controls, the slope adjustment will always pivot about the downstream control point.

$$Z_{deg} = L\,(S_o - S_{eq}) \tag{5.3}$$

where: L = Reach length from point of interest to downstream pivot point
S_o = Existing slope
S_{eq} = Equilibrium slope.

If the amount of levee toe-down appears excessive because of long term degradation, consider alternatives such as implementation of grade control structures along the channelized reach.

(b) General Scour *(Z_{gs})*

For a given flood event with a given duration, the volume of the sediment deposited or eroded in a channel reach is simply the difference between the upstream sediment supply rate and the channel sediment transport rate. If the supply rate is greater than the transport rate, the reach aggrades. The aggradation must be considered in the design of the levee freeboard height (*FB*) (see Section A-3). If the transport rate is greater than the supply, general scour will occur. Any scour that results from this phenomenon must be considered in the design of the total levee toe-down dimension *(Z_{tot})*.

Utilization of a sediment routing model (e.g. QUASED[1], HEC-6[2], FLUVIAL-12[3]) of the stream system is the best method of estimating the potential general scour (or general aggradation) on a reach by reach basis. However, less elaborate methods using rigid bed hydraulic and sediment transport calculations may be used to estimate the imbalance between sediment-transport capacity and sediment supply between adjacent reaches.

The curve in Appendix Q-3 may also be used to estimate the general scour for the proposed flow velocity.

(c) Local scour (Z_{ls})

Local scour occurs in the vicinity of an obstruction to flow, such as bridge piers, embankments, and contractions. Maximum local scour occurs during peak flow, therefore, use the peak capital flood (Q_{cap}) to determine the local scour (Z_{ls}) for the particular obstruction.

Pier Local Scour:

Appendix Q-4 shows the relationship between pier width *(b)*, in feet, and local scour (Z_{ls}), in feet, for square-nose piers. The different curves are for different velocities upstream of the bridge piers.

Scour depth adjustment factors (K_1) for pier shape other than square nose are presented in the following table:

Type of Pier	Reduction Factor K_1
Square nose	1.0
Round nose	0.9
Cylinder	0.9
Sharp nose	0.8
Group of cylinders	0.9

Table 5.1

[1] Quasi-Dynamic Sediment Routing Model - Developed by Simons, Li and Associates, Inc.

[2] Scour and Deposition in Rivers and Reservoirs - Developed by U.S. Army Corps of Engineers

[3] Mathematical Model for Erodible Channels - Developed by Howard H. Chang, Ph.D.

The angle of attack of oncoming flow has a significant impact on the potential scour depths. The local scour depth *(Z_{ls})* from Appendix Q-4 is adjusted by the appropriate factor *(K_2)* from Appendix Q-5. Appendix Q-5 shows the relationship between the angle of attack *(a)*, in degrees, and the local scour adjustment factor *(K_2)*. Several curves are shown for different pier length to width ratios *(L/b)*, where *L* is the length of the pier, and *b* is the width of the pier, both in feet.

Another adjustment *(K_3)*, is needed to account for debris blockage around the pier.

$$K_3 = \left(\frac{b + d}{b} \right)^{0.65} \tag{5.4}$$

where: d = Debris blockage, in feet.

Use four feet of debris blockage where a heavy floating debris load can be expected. Otherwise discuss with the Department's Hydraulic/Water Conservation and Design Divisions.

$$Pier\ local\ scour = Z_{ls} \times K_1 \times K_2 \times K_3$$

(see Example 3 in Appendix R).

Note:

1. Footings supported on soil or degradable rock strata shall be embedded below the maximum computed scour depth.

2. Footings on piles may be located above the lowest anticipated scour level provided that the piles are designed for maximum scour condition. For earthquake loading, assume only half of the maximum anticipated scour has occurred. For this case, a concept must be approved by the Department prior to proceeding with design.

Abutment Local Scour:

Estimate the depth of local scour at sloping-wall bridge abutments from the graph in Appendix Q-6. The graph shows the relationship between the length an abutment protrudes into the flow path *(a)*, in feet, and the depth of local scour *(Z_{ls})*, in feet. Several curves are shown for different velocity *(V)* and depth *(Y)* combinations.

Appendix Q-6 is applicable to non-vertical walled abutments with embankment projection *(a)* less than 25 times the depth *(Y)*. If the abutment terminates at a vertical wall, then multiply the scour depth *(* Z_{ls} *)* estimated from Appendix Q-6 by a factor of 2.0.

<u>Levee Local Scour:</u>

For soft bottom channels where the flow may possibly carry large debris (tree logs, boulders, etc.), increase the levee toe-down depth by 2 feet to account for local scour.

(d) Bend Scour *(*Z_{bs} *)*

This is the scour induced on the channel bed along the outside banks of channel curves.

Graphs in Appendix Q-7A-C show the relationships between the ratio of the channel top width to radius of curvature *(W/R)* and the bend scour *(* Z_{bs}*)*, in feet, for three different energy slopes *(* S_e *)*. Energy slope *(* S_e *)* is the slope of the energy gradient. Several curves are shown in each graph for different velocity *(V)* and depth *(Y)* combinations.

The secondary currents which create bend scour extend for some distance beyond the downstream end of the channel bend. The relationship between the depth of flow within channel bend *(Y)*, in feet, and the extent of scour downstream of channel bend *(X)*, in feet, is shown on the graph in Appendix Q-8.

(e) Low Flow Incisement *(* Z_i *)*

The best means of estimating the likely depths of incisement is through field inspection by measuring the low flow channel depth. For design purposes use Z_i equal to measured low flow depth, or 2 feet, whichever is greater.

(f) Bed Form Height *(h)*

Bed forms (dunes and antidunes) commonly develop in natural or man-made channels with sand beds. The distance between the mean bed elevation and the trough of the bed form is approximately equal to the distance from the mean bed elevation to the bed form crest, and the sum of these two distances is termed the bed form height.

The relationship between the mean channel velocity *(V)*, in feet per second, and the bed form height *(h)*, in feet, is shown on the graph in Appendix Q-9.

If the bed form height *(h)* from Appendix Q-9 exceeds the flow depth, use the flow depth instead.

<u>Total Toe-Down Requirement</u> *(Z_{tot})*:

Levee toe-down, as stated in Equation 5.2, is the total of long-term degradation *(Z_{deg})*, general scour *(Z_{gs})*, bend scour *(Z_{bs})*, local scour *(Z_{ls})*, half the bed form height *(½ h)*, and low flow incisement *(Z_i)*.

Compare to the levee toe-down computed using the Department's Hydraulic Design Manual criteria Section F and use the larger value.

A-3. <u>Embankment Protection (Levee Height)</u>

The levees must be designed to contain the design flood plus adequate freeboard.

Freeboard is the vertical distance from the water surface elevation to the top of the levees. Freeboard represents the additional height required to ensure overtopping does not occur from factors not accounted for in the design water surface calculations. These factors include possible long-term aggradation, superelevation at curved channels, and bed forms, in addition to less identifiable components such as separation, excessive turbulence, wave action and variations in loss coefficients.

Use a larger Manning's *n* to compute water surface elevations for design of levee height. Manning's *n* cannot be determined based on vegetation coverage alone. It is a function of many other variables including sediment size distribution, surface roughness, channel irregularity, obstructions, channel alignment and slope, and flow characteristics such as discharge, depth, and velocity. These variables change from one site to another; therefore, a generic description of the type and density of vegetation with relation to *n* is not feasible. Several references, such as <u>Open Channel Hydraulics</u> by Ven Te

Chow, provide methodologies to determine the appropriate n taking all these variables into consideration.

Freeboard allowance is defined as:

$$FB = Y_{agg} + Y_{ga} + Y_{se} + \frac{1}{2}h \tag{5.5}$$

where:
FB = Total freeboard
Y_{agg} = Long-term aggradation
Y_{ga} = General aggradation
Y_{se} = Superelevation
h = Bed form height (from Appendix Q-9).

Superelevation may be determined through application of the appropriate formula listed in Section C-3.1 of the Department's Hydraulic Design Manual. Other components may be estimated with the same techniques presented in Section A.2.

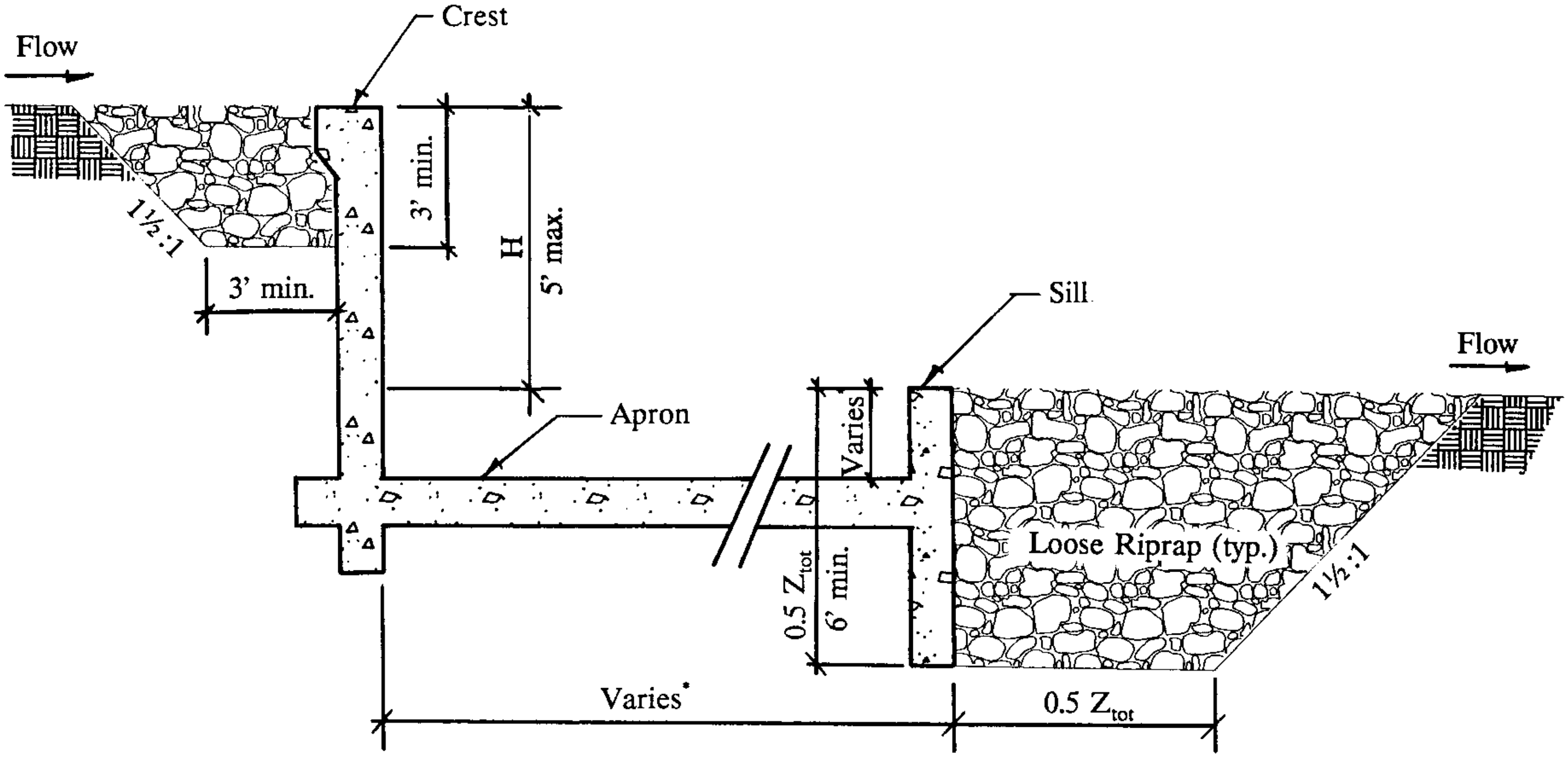
Compare to the freeboard computed using the Hydraulic Design Manual criteria Section F and use the larger value.

B. SOFT-BOTTOM CHANNELS WITH LEVEES AND STABILIZERS

Appropriate stabilization measures such as drop structures or point stabilizers may be required for soft-bottom channels. Appendix Q-2 shows the allowed percent increase in velocity corresponding to the natural slope. Appendix Q-2 has three curves to account for reduction in sediment supply that can result from sediment trapping facilities or gravel mining operations. If percent increase in velocity is higher than the allowable (above the curves) then invert stabilization is required.

B-1. Drop Structures

Drop structures (see Figure 5.1) are generally a conventional design with some type of stilling pool below the drop. The channel invert between the drop structures is graded to the design slope. (See Example 4 in Appendix R.)



* Dimension varies depending on hydraulic conditions.

Not To Scale

DROP STRUCTURE

FIGURE 5.1

The primary function of a drop structure is to decrease the gradient of a channel to create a condition of equilibrium (sediment inflow equal to sediment outflow). It also controls lateral bank migration and improves bank stability.

The recommended maximum nominal height *(H)* for drop structures is typically five feet.

Place riprap downstream and upstream of the drop structure to reduce the effect of local scour. The mean riprap size is a function of the flow velocity. Appendix Q-10 shows the relationship between the bottom velocity and the required riprap size. If channel velocity is beyond the range of the graph in Appendix Q-10, an additional energy dissipation measure will be necessary other than riprap.

B-2. Point Stabilizers

The primary function of a point stabilizer (see Figure 5.2) is to maintain the stability of the natural stream bed by controlling headcutting. The stabilizers are set at natural grade and buried to a sufficient depth to account for the scouring action that can occur during peak flows.

B-3. Drop Height and Spacing

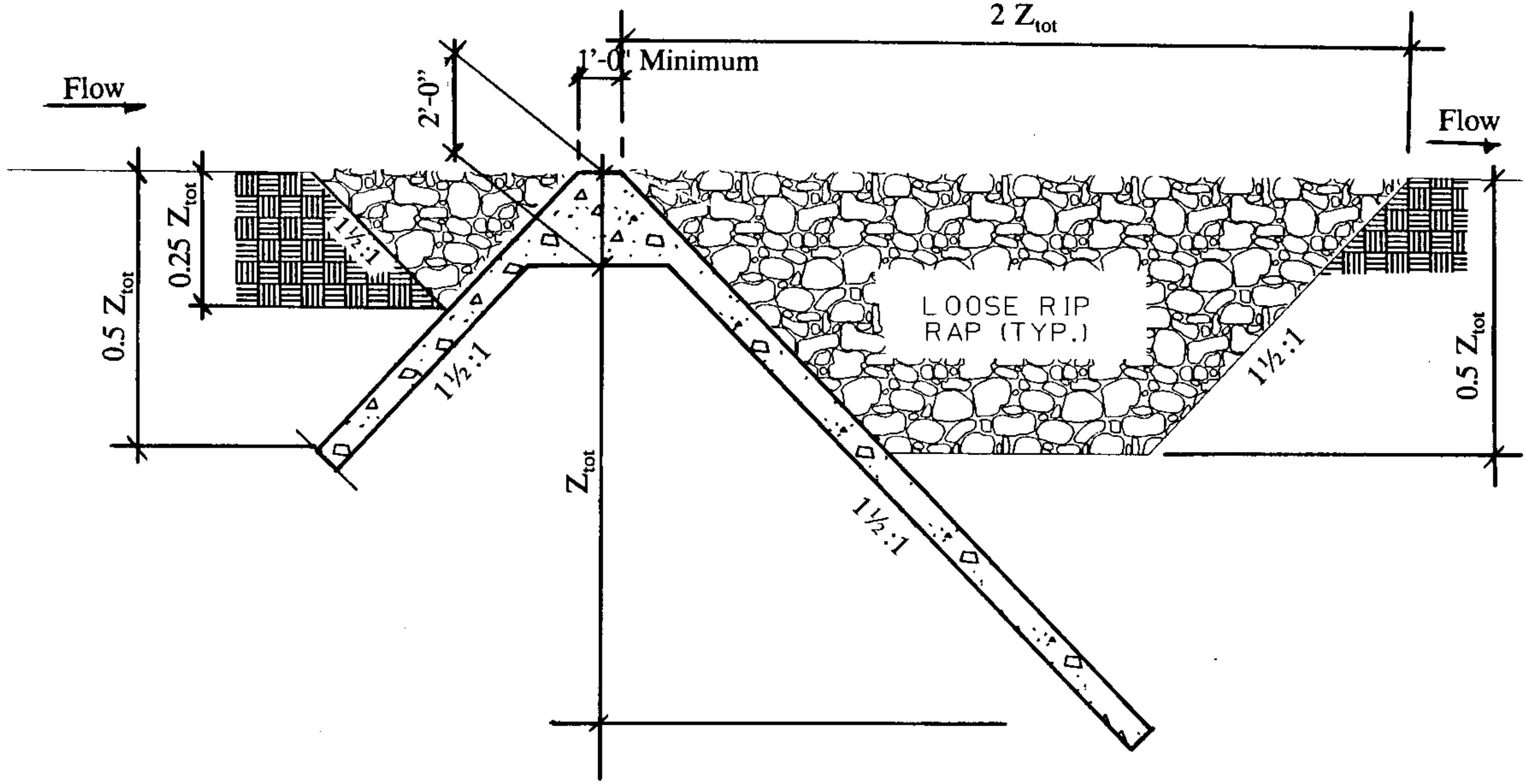
The design of grade-control structures is dependent upon the existing slope of the channel, the equilibrium slope (design slope) of the channel, the distance downstream to the nearest stable point in the channel, and the estimated scour hole depth below the structure under design flow conditions.

Determine the spacing of the invert stabilizers *(D)*, from the following equation:

$$D = \frac{H}{(S_o - S_{eq})} \tag{5.6}$$

where: D = Distance to the nearest downstream stable point
H = Nominal height of grade control structure, 2' maximum for point stabilizers and 5' maximum for drop structures.
S_o = Existing channel slope
S_{eq} = Equilibrium channel slope.

Provide access ramps between invert stabilizers for channel maintenance.



POINT STABILIZER

FIGURE 5.2

Not To Scale

C. HARD-BOTTOM (REINFORCED CONCRETE) CHANNELS

In the following cases a soft bottom channel is not feasible, and a concrete channel is needed:

(a) Sediment supply to the channel is significantly reduced or eliminated as in the case of a debris basin or a gravel mining operation.

(b) The invert slope is so steep that stabilizing the channel is unfeasible.

To limit invert abrasion in concrete channels carrying sediment, design the channel based on the following criteria:

(a) Velocity of debris carrying flow shall not exceed 40 fps.

(b) Design shall comply with the Department's Structural Design Manual, Sections G-9 (steel clearances and additional cover over the reinforcing steel).

Concrete channels must be designed to prevent sediment deposition which would reduce conveyance capacity. Deposited sediment has the dual impact of raising the bed level while increasing the roughness of the channel bed which increases the channel flow resistance.

The minimum velocity required to keep the channel clear of sediment is known as the limiting deposit velocity (V_l). Graphs in Appendix Q-11 show the relationship between the size of sediment for which 85 percent of the sediment is finer (d_{85}) and the limiting deposit velocity (V_l) in fps.

Follow the requirements listed in Table 5.2 for design of concrete channels carrying bulked flow.

D. CLOSED DRAINS

The minimum velocity required to keep the conduit clear of sediment is known as the limiting deposit velocity (V_l). Graphs in Appendix Q-11 show the

	Open Concrete Channel	Bulked Flow Inlet with Closed Conduit
General Location		Do not locate a closed conduit drain under homes or other permanent structures. Provide a safe secondary overflow path for water and sediment.
Horizontal Alignment		The horizontal alignment of the storm drain shall be straight[1].
Trash Barrier		A trash rack per LACDPW 3089-0 is required at the inlet. Trash posts spaced at 2/3 the diameter of the conduit or 4 feet, whichever is smaller, are also required.
Access Roads	Provide a vehicular access road of at least 12-feet wide within a 15-foot easement, paved with 3 inches of asphalt concrete (A.C.) over 4 inches of crushed aggregate base (C.A.B.) on both sides of the channel.	Provide a vehicular access road of at least 12-feet wide within a 15-foot easement, paved with 3 inches of asphalt concrete (A.C.) over 4 inches of crushed aggregate base (C.A.B.).
Hydraulic Design	Refer to the Department's Hydraulic Design Manual.	Refer to the Department's Hydraulic Design Manual. Pressure flow is not permitted in closed conduits.
Ponding		Ponding is not allowed at the inlet.
Freeboard	Refer to the Department's Hydraulic Design Manual.	Minimum freeboard at the inlet is 2-feet above maximum water surface elevation. Minimum freeboard to the soffit of the conduit is 1-foot.
Design Capacity	Channel or inlet and drain must be sized to pass the burned and bulked flow rate or the fully developed watershed flow rate whichever is higher.	
Drain Size		Minimum drain size is 36-inch RCP.
Drain Slope		The minimum drain slope shall be 5 percent. The slope shall be uniform to maintain uniform velocities. [2]
Structural Design	Refer to the Department's Structural Design Manual requirements for sediment carrying channels and conduits in regard to additional cover over the reinforcing steel.	
Minimum and Maximum Velocities	Peak flow velocity shall be greater than the limiting deposit velocity for the size of material to be transported (see Appendix Q-11) but shall not exceed 40 fps.	
Junctioning	Angle of confluence shall not exceed 5E45'.	Drains carrying less than 250 cubic yards of sediment may be allowed to junction with the mainline provided the total cumulative sediment is less than 1,000 cubic yards. The design concept must be approved by the Department prior to proceeding to final plans
Inlet Design	Design the inlet to the concrete channel or conduit to accelerate flows into the drain. Provide a minimum slope of 2% for the invert slab.	

Table 5.2

Footnotes:

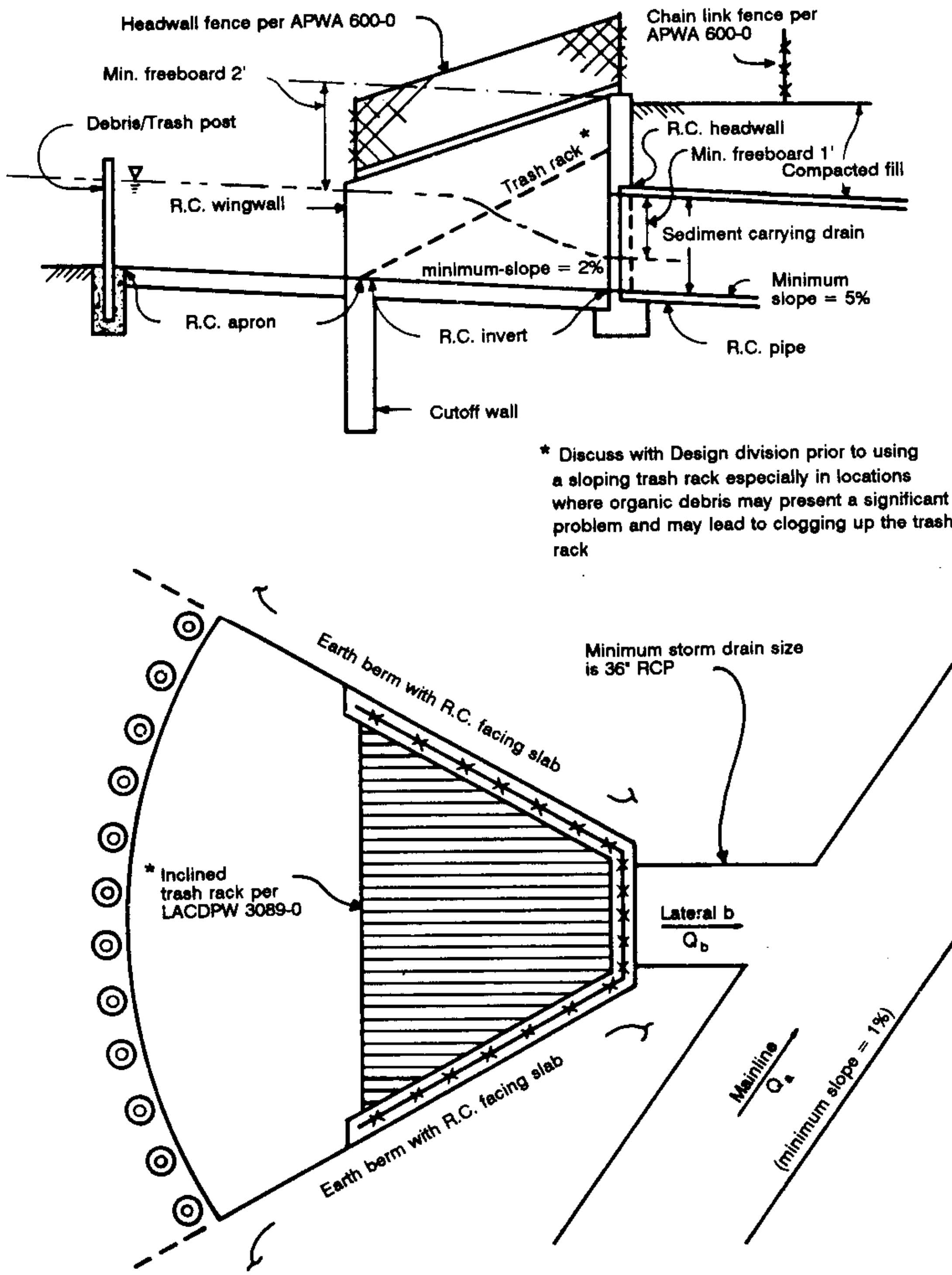
[1] If bends are unavoidable, the radius of curvature shall be at least 30 times the width of pipe. The central angle shall not exceed 45 degrees. The maximum deviation computed by the ratio: actual length from inlet to outlet/junction ove straight line distance from inlet to outlet/junction, shall be less than 1.1.

[2] A drain slope of 3 to 5 percent may be permitted provided the velocity is greater than the limiting deposit velocity (V_l).

relationship between the size of sediment for which 85 percent of the sediment is finer (d_{85}) and the limiting deposit velocity (V_l) in fps.

Closed conduits carrying bulked flow may be used according to the conditions in Table 4.1 for inlet with bulked flow drain. The design concept must be approved by the Department prior to proceeding to final plans. Follow the requirements listed in Table 5.2 for design of closed conduits carrying bulked flow.

Watersheds producing 1,000 cubic yards of sediment or greater require the use of an open channel (see Section C) or a sediment control facility (see Section 4). See Figure 5.3 for a typical sediment carrying inlet and drain. (See Example 5 on Appendix page R-13.)



SEDIMENT CARRYING INLET AND STORM DRAIN

FIGURE 5.3

E. INLET AND OUTLET DESIGN

E-1. Transition Design

FROM	TO	DESIGN CONSIDERATIONS
Soft bottom channel	Hard bottom channel	• Provide adequate cut-off at beginning of concrete channel • Increase inlet slope to accelerate the flow to limiting deposit velocity *(V_l)* • Provide smooth transition angles • If transition is from an unimproved channel, extend wing walls to the floodplain limits
Hard bottom channel	Soft bottom channel	• Use energy dissipation structure to reduce velocities to natural velocity • If concrete channel outlets into an unimproved soft bottom channel, design the outlet to direct the flow to its natural path. Extend wing walls to flood plain limits
Unimproved channel	Stabilized soft bottom channel	• Extend wing walls to flood plain limits • Provide invert stabilizer at beginning of stabilized channel to control the grade • Provide smooth transitions
Stabilized soft bottom channel	Unimproved channel	• Design the outlet to direct the flow back to its natural path • Provide invert stabilizer at the end of stabilized channel to control the grade
Hard bottom channel	Hard bottom channel	• Keep velocities above limiting deposit velocity and below 40 fps

Table 5.3

E-2. Energy Dissipation

Storm drains and channels which outlet into a natural or improved soft bottom channel will generally require an energy dissipator to reduce velocities to a non-erosive magnitude. The type of dissipator structure depends on the approach velocity and the desired natural velocity. Consult the Department's Design Division for type and design of energy dissipation structure.

In case of sediment laden-flows (bulked flow), the sudden drop in velocity usually causes deposition to occur at and upstream of the energy dissipation structure. Design the dissipator structure to minimize deposition and include provisions for access to remove the deposited sediment.

F. FLOODPROOFING OF DEVELOPMENTS IN NATURAL WATERCOURSES

Developments within the natural watercourse boundaries (that have been approved by Land Development Division) requiring floodproofing should follow the criteria in Section A to determine the scour depth and embankment height of local protection. Developers must prove through use of hydraulic and sediment transport analyses that their development will not have any adverse effect on neighboring properties such as increased flood hazard, scour or deposition. Contact Land Development and Planning Divisions for the Department's drainage requirements.

LIST OF SYMBOLS

SYMBOL		DEFINITION
A	=	Total drainage area, including developments
A_i	=	Individual drainage area
A_u	=	Total undeveloped area
A_d	=	Total developed area
A_{di}	=	Developed area, in area A_i
a	=	Bulking constant (fixed throughout the hydrograph)
a	=	Length which abutment protrudes into the flow
a	=	Angle of attack
BF	=	Bulking factor
$BF_{(Ai)}$	=	Bulking factor based on area, A_i
b	=	Pier width
C	=	Capacity of sediment control structure
D	=	Distance to the nearest downstream stable point
d	=	Debris blockage
DP	=	Debris production
DPA	=	Debris potential area
DPR	=	Debris production rate
$DPR_{(A)}$	=	Debris production rate based on the total drainage area A
$DPR_{(Ai)}$	=	Debris production rate based on area, A_i
$DPR_{(Au)}$	=	Debris production rate based on the total undeveloped drainage area, A_u
$DPR_{i(Ai)}$	=	Debris production rate based on area A_i in DPA zone i
d_{85}	=	Size of sediment for which 85 percent of the sediment is finer
FB	=	Total freeboard
G	=	Multiplication factor
g	=	Acceleration of gravity
H	=	Nominal height of grade control structure
H_c	=	Height of debris cone
H_s	=	Height of spillway above natural ground
h	=	Bed form height
L	=	Reach length
L	=	Length of pier
K_1	=	Scour depth adjustment factor
K_2	=	Local scour adjustment factor

SYMBOL		DEFINITION
K_3	=	Local scour depth adjustment factor to account for debris blockage around pier
n	=	Bulking exponent (fixed throughout the hydrograph)
n	=	Manning's roughness coefficient for the channel
Q	=	Clear or burned discharge
Q_B	=	Bulked or burned and bulked discharge
Q_b	=	Bulked flow discharge
Q_{cap}	=	Department's Capital Flood discharge
Q_s	=	Sediment discharge
$Q_{S\ in}$	=	Sediment supply into the reach
$Q_{S\ out}$	=	Sediment transport out of the reach
Q_w	=	Water discharge (clear or burned)
Q_{10}	=	10 year runoff discharge
R	=	Radius of curvature
S_o	=	Existing slope
S_e	=	Energy slope
S_D	=	Sediment/Debris cone slope
S_{eq}	=	Equilibrium slope
S_g	=	Specific gravity
S_N	=	Natural slope of the stream
V	=	Velocity of flow
V_l	=	Limiting deposit velocity
V_{lmax}	=	Maximum limiting deposit velocity
W	=	Channel top width
Y	=	Depth of flow
Y_{agg}	=	Long-term aggradation
Y_{ga}	=	General aggradation
Y_{se}	=	Superelevation
Z_{bs}	=	Bend scour
Z_{deg}	=	Long-term degradation
Z_{gs}	=	General scour
Z_i	=	Low-flow incisement
Z_{ls}	=	Local scour
Z_{tot}	=	Total potential vertical adjustment

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Chow, Ven Te, Open Channel Hydraulics

Ferrel, William F., Los Angeles County Flood Control District report published in November 1959 on "Debris Reduction Studies for Mountain Watersheds"

Simons, Li & Associates, "Fluvial Study of the Santa Clara River and its Tributaries" prepared for the Los Angeles County Department of Public Works, November 1990

[1] This is a partial list.